

東京帝國大學紀要

理 科

第 拾 壹 冊

THE JOURNAL

OF THE

COLLEGE OF SCIENCE,
IMPERIAL UNIVERSITY OF TŌKYŌ,
JAPAN.

VOL. XI.

東 京 帝 國 大 學 印 行

PUBLISHED BY THE UNIVERSITY.

TŌKYŌ, JAPAN.

1898—1899.

MEIJI XXXI—XXXII.

Publishing Committee.



Prof. **K. Yamagawa**, *Ph. B.*, *Rigakuhakushi*, Director of the College
(*ex officio*).

Prof. **J. Sakurai**, *Rigakuhakushi*.

Prof. **B. Kotô**, *Ph. D.*, *Rigakuhakushi*.

Prof. **I. Ijima**, *Ph. D.*, *Rigakuhakushi*.



All communications relating to this Journal should be addressed to the
Director of the College of Science.

CONTENTS.

Pt. I. Published Nov. 5th, 1898.

Preparation of Hyponitrite from Nitrite through Oxamido-sulphonate. By E. DIVERS, <i>Prof., M.D., D.Sc., etc.</i> and T. HAGA, <i>D.Sc., etc.</i>	1
Absorption of Nitric Oxide in Gas Analysis. By E. DIVERS, <i>Prof., M.D., D.Sc., etc.</i>	9
Interaction of Nitric Oxide with Silver Nitrate. By E. DIVERS, <i>Prof., M.D., D.Sc., etc.</i>	11
Preparation of Pure Alkali Nitrites. By E. DIVERS, <i>Prof., M.D., D.Sc., etc.</i>	15
The Reduction of an Alkali Nitrite by an Alkali Metal. By E. DIVERS, <i>Prof., M.D., D.Sc., etc.</i>	19
Hyponitrites: their Properties and their Preparation by Sodium or Potassium. By E. DIVERS, <i>Prof., M.D., D.Sc., etc.</i>	33

Pt. II. Published March 14th, 1899.

On the Geologic Structure of the Malayan Archipelago. By B. KOTÔ, <i>Prof., Ph.D., etc.</i> (<i>With Plate I</i>)	83
---	----

Pt. III. Published June 10th, 1899.

Horizontal Pendulums for the Mechanical Registration of Seismic and Other Earth Movements. By F. OMORI, <i>Prof., D.Sc.</i> (<i>With Plates II-XII</i>)	121
Note on the Preliminary Tremor of Earthquake Motion. By F. OMORI, <i>Prof. D.Sc.</i> (<i>With Plates XIII-XVI</i>)	147
Earthquake Measurement at Miyako. By F. OMORI, <i>Prof. D.Sc.</i> , and K. HIRATA. (<i>With Plates XVII-XXIII</i>)	161
Ethyl ammoniumsulphite. By E. DIVERS and M. OGAWA	197

Ethyl ammonium selenite and Non-existence of Amidosele- nites (Selenosamates). By E. DIVERS and S. HADA...	205
Notes on the Minerals of Japan. By K. JINBO, <i>Prof., Rigaku-</i> <i>hakushi</i>	213

Pt. IV. Published Dec. 8th, 1899.

On the Mutual Influence between Longitudinal and Circu- lar Magnetizations in Iron and Nickel. By K. HONDA, <i>Rigakushi.</i> (<i>With Plates XXIV and XXV</i>)	283
The Earthquake Investigation Committe Catalogue of Japanese Earthquakes. By S. SEKIYA, <i>Prof.</i>	315
Notes on the Earthquake Investigation Committee Catalo- gue of Japanese Earthquakes. By F. OMORI, <i>D.Sc.</i> (<i>With Plates XXVI-XXXVII</i>)... ..	389

Preparation of Hyponitrite from Nitrite through Oxyamidodisulphonate.

By

Edward Divers, M. D., D. Sc., F. R. S., Prof.,

Imperial University, Tokyo,

and

Tamemasa Haga, D. Sc., F. C. S.

Through sulphonation followed by hydrolysis, an alkali nitrite is readily converted into the unstable oxyamidodisulphonate, which, in a solution saturated with potassium hydroxide, gets all its hydrogen replaced by potassium and is at the same instant resolved into hyponitrite and sulphite— $2\text{HONH} \cdot \text{SO}_3\text{Na} + 4\text{KOH} = (\text{KON})_2 + 2\text{KSO}_3\text{Na} + 2\text{OH}_2$. This remarkable change was made known by us in 1889 (this Journal, **3**, 211), along with the fact that in it a rich source of hyponitrite had been lighted upon, since at least half the quantity of hyponitrite equivalent to the nitrite taken could be secured. But this productiveness, it was pointed out, depended upon our method of getting oxyamidodisulphonate being employed, and the description of the method was not published till five years later, before when, consequently, the new source of hyponitrite could not be used advantageously by others. Even since then the method has escaped the notice of seven separate workers upon hyponitrites, Thum, W. Wislicenus, Paal and Kretschmer, Tanatar, D. H. Jackson, Piloty, and Hantzsch and Kaufmann, to be at last, however, taken up by Kirschner (*Z. anorg. Chem.*, 1898, **16**, 424). Indeed, it may be said to have been rediscovered by Piloty, who, in a paper upon ‘an oxidation of hydroxylamine by benzenesulphonic chloride,’ (*Berichte*, 1896, **29**, 1559), de-

scribes the resolution of benzenesulphonic hydroxylamide by potassium hydroxide into hyponitrite and benzenesulphinate, with a yield also of half the calculated quantity of the former salt.

As we have, each of us, very many times practised the oxyamidosulphonate method of getting hyponitrite and have not published the details of work which must be attended to in order to get high yields, it seems to us that we shall be doing a service by describing how to work the process.* After so much experience, we ourselves can count on getting a yield of sixty per cent. of the theoretical quantity (occasionally getting much more but without discovering how we had been so successful). The full quantity of silver hyponitrite would be just twice the weight of the sodium nitrite, while we get one-and-a-fifth times its weight. In what follows we assume that the convenient quantity of 2 decigram-molecules of sodium nitrite is taken, from which about 17 grams of silver hyponitrite may be obtained.

In order to limit the quantity of potassium hydroxide required, which is very large in any case, no more water than is necessary must be used. Except for the particular attention to be given to this point, the process begins exactly like that of making hydroxylamine sulphate from nitrite (This Journal, 1896, **9**, 291). In a tared, wide-mouthed, round-bottomed flask of 200-250cc. capacity, 14.4 grams of 96 per cent. sodium nitrite,** together with sodium carbonate containing 10.6 grams of anhydrous carbonate, are dissolved by heat in enough water to

* Kirschner's method is an excellent form of our process, but I prefer that described in this paper.—E.D.

** But, preferably, 13.8 gr. pure sodium nitrite, this being now very easy to prepare (this vol. p. 15).

make the whole contents weigh 83.5 grams. (Some lead salt in the nitrite deposits, but goes into solution when the potassium hydroxide is added and gives no trouble). Sodium carbonate of any hydration may here be used but as, later on, more of this salt will be wanted and then should be approximately the monohydrate, it is convenient to use this form throughout. Such a carbonate, almost pure, is generally found in the 'dried' pure carbonate of commerce. Keeping the flask in active motion in an ice-and-brine bath, sulphur dioxide is passed in until a short time after the temporarily precipitated acid-carbonate has redissolved and when a bit of lacmoid paper in the solution becomes fully red. About $\frac{1}{10}$ cc. strong sulphuric acid is then dropped in. Thus carried out, always below 0° , the conversion of the nitrite into oximidosulphonate is perfect, while much above 3° some nitrilosulphonate would form and disturb everything. If such higher temperatures have been avoided, the nitrite and carbonate taken in close molecular proportions, and the sulphur dioxide not used in excess, the solution is ready to be hydrolysed; but as the proportions of the salts may have been a little out and also sulphur dioxide be present, it is best to blow a strong current of air through the solution before its temperature has risen, so as to expel any sulphur dioxide or nitric oxide that may be present.

After this treatment, the solution is brought to about 30° , in order to start hydrolysis, then set aside for a day, in a warm place, with the flask corked. Complete hydrolysis to oxyamidosulphonate without further hydrolysis to hydroxylamine is thus secured,* and, consequently, just the calculated

*This success in avoiding production of hydroxylamine has been proved by shaking the solution, after it has been made alkaline, with sodium amalgam which readily converts

quantity of sodium carbonate (10.8 grams anhydrous) is found to be required, including that for the three or four drops of sulphuric acid added. The approximately monohydrated carbonate, in fine powder, is quickly shaken thoroughly with the solution, so as to hinder its caking, and the last portions of it then dissolved up by warming the flask. The solution of oxyamidosulphonate and sulphate, thus prepared, contains almost exactly only half its weight of water, is therefore supersaturated, and is the strongest solution practically obtainable; it will be found to approach closely 113 grams in weight, so smoothly do the reactions proceed. To make a weaker solution and then concentrate it by evaporation is easy enough, but the adjustment is troublesome and the formation of hard cakes of sodium sulphate, which interferes with the proper working of the next stage of the operation, is difficult to avoid.

The flask is well drained of its contents into a basin, preferably a hemispherical nickel basin or, lacking that, a stout porcelain one, of capacity not much less than 500cc. Potassium hydroxide, free from chloride, assayed for real alkali and for water, and having not less than $\frac{2}{3}$ and not more than 1 mol. water to 1 of the hydroxide, is now needed; for if it were anhydrous it would cause much heating and consequent decomposition of the salts. Generally, the potassium hydroxide purified by alcohol and the more translucent varieties of stick potash contain about the right proportion of water and then

hydroxylamine to ammonia and is inactive upon oxyamidodisulphonate. Testing in this way, no odour of ammonia has been recognisable and moist red litmus paper held in the bottle has been barely affected. Kirschner, using potassium oximidosulphonate, had to heat to boiling to effect hydrolysis, which is difficult then to complete without some of the oxyamidodisulphonate passing on into hydroxylamine. When the hydrolysis is underdone, there will be nitrite regenerated later on by the alkali; and when it is overdone there will also be nitrite formed during the oxidation of the hydroxylamine by the silver (or mercury) oxide.

dissolve in water without much rise of temperature. From 130 to 165 grams of it, according to its degree of hydration, are quickly crushed in a warm mortar and thrown into the solution in the basin and incorporated with it by means of a pestle. There is marked heating only just at first, which is better met by keeping the basin in water or resting on snow or pounded ice for a very short time. On stirring-in the potassium hydroxide the solution sets to a stiff paste, if kept cold, quickly becoming thin again by further stirring, but full of opaque white precipitate of sulphate. If the basin has been cooled, hardly any gas escapes at first, but gentle effervescence and much frothing occur before long in any case. When the potassium hydroxide has been all ground up and dissolved, the basin is placed under close cover from atmospheric moisture and carbonic acid, and left so for 30 hours in a warm place (Kept for more than 50 hours, the quantity of hyponitrite sensibly but slowly diminishes). As much even as one-fourth of the oxyamidosulphonate may sometimes in cold weather still be present and can be partly destroyed by keeping the basin at 55–60° for half an hour, though not with noticeable increase of the quantity of preserved hyponitrite. This heating, with the risk attendant on it of destructive over-heating, is better omitted, on the whole. Besides undecomposed oxyamidosulphonate, the contents of the basin now consist of precipitated sulphate and sulphite, and solution of potassium hydroxide in slightly less than its weight of water (almost exactly, $\text{KOH} : 3\text{H}_2\text{O}$), together with the potassium hyponitrite. It is, apparently, only to secure this concentration of the potassium hydroxide, a practically saturated solution, that hardly less than 10 mols. of it to one oxyamidosulphonate have to be used. More of it may

be added without effect, good or bad, unless the solution of the salts is weaker than it is here advised to be, for in that case additional potassium hydroxide must be taken to bring its concentration to the right point.

Treatment with a silver salt is the only way of separating the hyponitrite from the other salts, and for this purpose the presence of the alkali is essential, together with large dilution when precipitating. The best way is to use the silver solution exceedingly dilute, because this checks the precipitation of silver oxide and sulphite until some time after hyponitrite has been all separated. Now, the need for large dilution and the advantage of still larger dilution remove the only objection that can be raised to the use of silver sulphate instead of silver nitrate; and since it is generally important to feel assured that no trace of nitrate or nitrite can have been added to the hyponitrite, the sulphate should have the preference, although the nitrate can almost certainly be used with as good results. A cold saturated solution contains only 5 or 6 grams of the sulphate to the litre, and is most easily prepared by boiling excess of the salt with water and pouring the solution into an equal volume of cold water.

Whichever salt is used, the contents of the basin having been washed into a very capacious precipitating vessel, the highly dilute silver solution is poured in until it ceases to produce any more black precipitate. When this is at all abundant, as it sometimes is in winter weather, an hour's interval is given for subsidence of most of it, the still dark solution decanted, and the precipitate washed by decantation before rejection. With or without this interruption, the addition of the silver solution is continued until the bright yellow hypo-

nitrite suddenly appears, and so long after as the joint precipitation of brown oxide is easily checked by stirring. When the point is reached where the oxide only redissolves slowly and no longer gives place to a yellow one of hyponitrite, no more silver solution must be added. To add much more would be to cause permanent precipitation of silver oxide, which, if at all large in amount, is apt to be accompanied by silver sulphite. The quantity of silver sulphate needed may be as much as 40 grams, which means 7 or 8 litres of solution; of silver nitrate about 44 grams will be wanted, dissolved in 4 litres, or more, of water.

Half an hour after precipitation, the solution is to be poured off even though still a little turbid, and the precipitate washed by decantation; for very slowly deposition of a mirror of metallic silver from the sulphite in solution begins and goes on for days. In order to separate the hyponitrite from the metallic silver and its oxide, and perhaps chloride, it has to be dissolved in dilute acid and reprecipitated. If every trace of nitrite is to be kept out of the hyponitrite, nitric acid can hardly be used, because it always contains, according to my testing, a very minute quantity of nitrous acid. Sulphuric acid is therefore the acid to take. Since the hyponitrite must be kept in solution the shortest time possible for filtration, the use suggests itself of acid not very dilute in order to reduce the volume of liquid to be filtered. But high dilution is better, because the stability of hyponitrite falls off rapidly with increasing concentration, and, besides this, the use of sulphuric acid not dilute enough causes separation of silver sulphate. A one per cent. solution of the acid is suitable, after it has been well cooled in ice, some five litres of it being probably required.

The precipitate should be treated with the acid in portions at a time, not all together; and as far as possible undissolved precipitate should be kept off the filter till the last. For so long a filtration a Lunge's filter tube extension of the funnel is more suitable than the filter pump. The filtrate is to fall direct into excess of sodium carbonate solution. Working with these precautions, the silver hyponitrite can be dissolved and reprecipitated, even in hot weather, with hardly appreciable loss.

Having replaced the mother-liquor by water, dilute sulphuric acid is cautiously added until, after good stirring up of the precipitate, the solution is no longer alkaline and some of it filtered is found to contain dissolved a trace of the silver hyponitrite, this being best ascertained by adding one or two drops of sodium carbonate solution to about 100 cc. of it, which should cause a permanent yellow, very slight opalescence.

The precipitate, thoroughly washed by decantation and dried on a filter at the common temperature in a desiccator in the dark, and then at 100° , will give 78 per cent. silver (calc., 78.26). But in order to preserve the bright colour of the salt and its entire freedom from nitrite, all work upon it should be done with very little exposure to bright daylight. Its weight should be not less than 17 grams.



Absorption of Nitric Oxide in Gas Analysis.

By

Edward Divers, M. D., D. Sc., F. R. S., Prof.,
Imperial University, Tokyo.

It is well known that the vapour tension of nitric oxide, dissolved in the solution of a ferrous salt, interferes with the use of this reagent to remove nitric oxide from other gases. There is, however, another absorbent for nitric oxide which leaves nothing to be desired, whose use and value have remained unknown. This is a strong solution of either sodium or potassium sulphite, to which a little alkali hydroxide is added. It quickly absorbs every trace of nitric oxide, which it fixes in the form of hyponitrososulphate, $\text{Na}_2\text{N}_2\text{O}_3\text{SO}_3$. I have already made satisfactory use of it to analyse the mixture of nitric oxide and nitrogen which is left on heating silver hyponitrite and letting the solid and gaseous products cool in contact with each other. The sulphite need not be very pure, the presence of sulphate or carbonate being of no importance. If carbon dioxide or other acid gas is present with the nitric oxide, it is removed by alkali, before using the sulphite reagent.



Interaction of Nitric Oxide with Silver Nitrate.

By

Edward Divers, M. D., D. Sc., F. R. S., Prof.,
Imperial University, Tokyo.

Having reason to think that silver nitrate might interact with nitric oxide if heated in it, and there being no information obtainable on the point, I have been induced to make some experiments with silver nitrate, as well as other nitrates, and nitric oxide.

First, something had to be ascertained of the behaviour of silver nitrate when heated alone. Heated for fifteen minutes in dry air or carbon dioxide, it suffers no chemical change until the temperature is close to the melting point of sulphur (444°), and its slight decomposition at that temperature, being accompanied by its action upon the glass, may be due to that action. A minute quantity of oxygen seems to be liberated, and there is a very slight greying of the faintly yellow liquid. On cooling and dissolving, there is slight turbidity from the presence of silver, and a trace of nitrite can be detected. Only at a much higher temperature does the salt decompose with free effervescence, and then nitric peroxide accompanies the oxygen, and silver is deposited. Even then, nitrite is present in the mass only in very small quantity at any time, being never enough to remain insoluble when the nitrate is dissolved in a little water. This is sufficient, however, to show that the primary decomposition of silver nitrate, by heat alone, is into silver nitrite and oxygen; since the instability of silver nitrite at much lower temperatures, though diminished by the presence

of nitrate (*J. Ch. Soc.*, 1871, **24**, 85) fully accounts for its being found only in such small quantity when the temperature is high, and for the production of nitric peroxide and silver instead. As determined by Carnelley, the melting point of silver nitrate is 217° .

The nitric oxide used for the experiments was prepared by the ferrous-sulphate method, stored for two days in a glass gas-holder, and dried in its passage to the silver nitrate by a sulphuric-acid column. At starting, the air in the drying apparatus and in the tube containing the silver nitrate was expelled by carbon dioxide, the silver nitrate being heated in the gas, in order to dry it. Interaction between the silver nitrate and the nitric oxide was recognised by the reddening of the gas. At the end of an experiment the gases were expelled by carbon dioxide before opening the tube.

Silver nitrate heated in nitric oxide is greatly affected by it, being freely decomposed at much lower temperatures than those at which it decomposes by itself, while the nitric oxide becomes oxidised. The action commences perhaps at 150° , but this is doubtful; at the melting point of the salt it becomes marked and interaction at the boiling point of mercury considerable; but even at this temperature it is a long time before the decomposition becomes complete, the progress of the change growing slower. For some time the products are silver nitrite and nitric peroxide— $\text{AgNO}_3 + \text{NO} = \text{AgNO}_2 + \text{NO}_2$, with only very little silver, the nitrite being almost wholly preserved for a long time through combination with the undecomposed nitrate. But when by the consumption of the nitrate the nitrite gets unprotected it suffers spontaneous decomposition as usual into silver and nitric peroxide. At last, nothing but silver remains.

Theoretically, it is quite probable that nitric oxide does not, after all, act directly upon silver nitrate. For, making the allowable supposition that, to a minute extent, silver nitrate decomposes into silver nitrite and oxygen at temperatures much below that at which it does so sensibly, the nitric oxide may be regarded as active by combining with this oxygen and thus by removing it greatly hastening the spontaneous decomposition of the nitrate. This decomposition, thus assisted, occurring at temperatures at which silver nitrite is comparatively stable in presence of nitrate, the nitrite remains, though at higher temperatures it decomposes almost as fast as it gets formed from the nitrate. According to this theory, silver nitrate is not actually decomposed by nitric oxide, but only decomposes much more rapidly in its presence, in consequence of its interaction with one of the decomposition products. For practical purposes, silver nitrate and nitric oxide may however be treated as active upon each other when heated together.

Nitric oxide has no action upon sodium, potassium, or barium nitrate, even at the temperature of boiling sulphur.

Lead nitrate soon begins to decompose by heat alone and nitric oxide seems to be without effect upon its decomposition. According to Stas, lead nitrate begins to decompose somewhere above 200° . I find that, for its fairly free decomposition, a temperature not much below 400° is required. At the boiling point of sulphur, even, the decomposition proceeds at such a moderate rate that only after ten minutes heating does the salt show distinct signs of fusing. No nitrite is produced, but there is formed a very little peroxide of lead. By washing the mass with cold water and then boiling it out with water, abundance of the beautiful, crystalline, white salt, $\text{Pb}(\text{OH})\text{NO}_3$, is obtained.

Preparation of Pure Alkali Nitrites.

By

Edward Divers, M. D., D. Sc., F. R. S., Prof.,
Imperial University, Tokyo.

When pure sodium or potassium nitrite is wanted, it is customary to prepare silver nitrite from crude alkali nitrite, and convert this again into alkali nitrite by means of sodium or potassium chloride. The crude nitrite must be nearly free from sulphate and, either before or after adding the silver nitrate to it, nitric acid must be added till all hydroxide and carbonate are neutralised. The silver nitrite is got in the most convenient form for washing by precipitating it from concentrated solutions. Silver chloride is very sensibly soluble in a concentrated solution of alkali nitrite, and when the solution is no longer clouded by the addition of more alkali chloride, it already contains this salt in excess. Therefore, somewhat large dilution is necessary and this entails, of course, much evaporation afterwards.

The silver nitrite process is evidently not a very satisfactory one, and when sodium nitrite is wanted pure, it is better to recrystallise, three times over, the commercial 96 per cent. sodium nitrite, well draining each time on the suction funnel. A concentrated solution of the crude salt should be left to clear from lead-turbidity for two days or be filtered cold through a fine filter. The lead carbonate is more soluble in the hot nitrite solution than in the cold. After separating the lead,

the solution should be fully neutralised with nitric acid, before evaporation for crystallising. Potassium nitrite is too soluble and deliquescent to be conveniently purified in a similar way.

A most satisfactory and simple process for preparing either sodium or potassium nitrite, when the pure hydroxide or carbonate is at command, is to saturate this with red fumes under appropriate conditions. That nitrites can be thus obtained is known to every chemist, was known to Gay-Lussac in 1816, and was described by Fritzsche in 1840, but it has hitherto been stated and believed that much nitrate is then unavoidably formed along with the nitrite. That is a mistake, and therefore this note is published. If obvious precautions of the simplest kind are taken, so little nitrate, if any, is formed, as to be hardly detectable with certainty in presence of so much nitrite. Consequently, if the quantity of pure alkali taken is known, a solution of given strength in nitrite is perhaps better prepared in this way than in any other.

Avoiding so far as practicable, the use of cork and caoutchouc, nitrous gases, from nitric acid and starch or arsenious oxide, are passed into the concentrated solution of the hydroxide or carbonate until the alkali is quite neutralised. Sodium carbonate alone is somewhat inconvenient, because of its sparing solubility, but this may be circumvented by adding it, finely divided and in sufficient quantity, to its own saturated solution just before passing the gases, and by often shaking the vessel during their absorption. To prevent free access of air, the nitrite is prepared in a flask with its mouth kept loosely closed, while the gases are passing. Cooling the flask is not necessary. The strength of the nitric acid and the temperature of the generation of the nitrous gases must be so regulated that just

a little nitric oxide is in excess of the nitric peroxide, and therefore is passing unabsorbed, as a guarantee that the latter does not act upon the solution in absence of its equivalent of the former and thus produce some nitrate. To free the gases from volatilising nitric acid they may be passed through a bottle or tube, either empty or packed loosely with cotton. The finished solution must be almost neutral; if acid, it is to be boiled till neutral, before exposing it to the air. A concentrated solution of alkali nitrite dissolves a little nitrous acid without decomposing it, as water alone would. To get the salt in the solid state or to crystallise out the sodium nitrite, where it is necessary to be sure of absence of all nitrate in it, the solution may be freely evaporated, even at a boiling heat, without decomposing or oxidising it.

The alkali nitrites have been very imperfectly described, and need examination. In the mean time, some points in their description are here given. Sodium nitrite and potassium nitrite are distinctly though faintly yellow and give markedly yellow solutions in a little water. They are very slightly alkaline to litmus. At 15° sodium nitrite, 5 parts, requires water, 6 parts, to dissolve it. Potassium nitrite is soluble in about one-third of its weight of water. Sodium nitrite melts at 271° (mercury thread immersed). Sodium nitrite is moderately deliquescent, remaining dry in winter-cold weather. Potassium nitrite is exceedingly deliquescent. This nitrite is got in very small, thick, prismatic crystals, but sodium nitrite crystallises in very thin, flattened prisms, often very large. Sodium nitrite is well known to be anhydrous; not so, potassium nitrite, crystals of which are reputed to contain half a molecule of water. I have examined small, but distinct and separate, crystals, taken from

the upper part of some kilos. of the commercial salt, which had become well drained by long standing. They were removed in very dry weather and weighed, and then found to lose hardly one per cent. on fusion. The anhydrous character of the salt was further ascertained by heating a cake of minute crystals, prepared by myself, which had been pressed, under cover, between porous tiles, in cold dry air. The loss of weight on heating, much above 100° , was a little over one per cent., and the percentage of potassium was 45.30, instead of 45.88, required for the anhydrous salt.

Somewhat remarkably, the point as to hydration of potassium nitrite was examined independently in the same year, 1863, by Lang and by Hampe, with identical results, indicating the composition expressed by $(\text{KNO}_2)_2, \text{OH}_2$. But then both chemists made the determination upon a magma of indistinct crystals, dried up in the vacuum-desiccator.



The Reduction of an Alkali Nitrite by an Alkali Metal.

By

Edward Divers, M. D., D. Sc., F. R. S., Prof.,
Imperial University, Tokyo.

What the products are which may result from the action of sodium amalgam upon solution of sodium nitrate or nitrite is already known. Schoenbein (1861) first observed the formation of nitrite by the action of metallic sodium upon solution of a nitrate; and de Wilde (1863) that nitrous oxide, nitrogen, and ammonia are the products of the action of sodium amalgam upon a solution of nitrate of potassium, sodium, or ammonium, or upon one of nitrite of potassium. He found that, except alkali hydroxide, nothing else is produced and in particular no hydrogen. But, some years after (1870), it was recognised by Fremy, aided by a suggestion of Maumené's, that hydroxylamine, or what appeared to be it, was a product of the reduction. Then came (1871) my own discovery of the hyponitrites, together with the observation that alkali nitrates in solution are largely convertible into nitrites by sodium amalgam, an extension of Schoenbein's experience. Lastly, Haga and I (1896) proved that the actively reducing substance observed by Fremy is actually hydroxylamine, as it had been taken to be by Maumené and him, and not hydrazine as it might have been. By a mistake, already pointed out and corrected by me (*Annalen*, 1897, **295**, 366) the discovery of the hyponitrites

has been in recent years attributed to Maumené. It will suffice here to say that this veteran French chemist has, it so happens, published, in another connection, that he had not experimentally investigated the reduction of nitrites in solution, and that, far from laying claim to the discovery of hyponitrites, he at first denied its truth on theoretical grounds. (*J. Ch. Soc.*, 1872, **25**, 772; *Chem. News*, **25**, 153 and 285).

Nitrous oxide, nitrogen, hydroxylamine, ammonia, sodium hyponitrite, and sodium hydroxide (from the nitrite as well as from the metal) are the substances always all produced, according to my experience, in the reduction of sodium nitrite or nitrate by sodium amalgam, but in proportions which greatly vary within well marked limits. Nearly one-sixth of the nitrogen can be obtained as sodium hyponitrite in one way of working or scarcely any at all in another. So, too, the range of production of hydroxylamine is from nearly 9 per cent. of the nitrogen of the nitrite down to a third per cent. The presence of ammonia may be very strongly manifest or be hardly perceptible and escape notice. The two gases, nitrous oxide and nitrogen, together represent at least 80 per cent. of the total nitrogen and may vary between themselves to the extent of either of them being nearly absent. Necessarily all the sodium not left as hyponitrite appears as hydroxide, along with that derived from the metallic sodium used as the reducing agent. So long as any nitrite remains, no hydrogen appears among the products, unless a very large quantity of water is present, while when there is exceedingly little water hydrogen is not formed even after all nitrite is gone.

Within the limits indicated, the proportioning of the products of the reduction is well under control. The concentra-

tion of the solution of nitrite or, to put it better the relative quantity of water present, exercises most influence; the only other circumstance affecting the course of the reduction is the temperature at which it is allowed to proceed. The concentration of the sodium in the amalgam and the proportions of the sodium and the nitrite are without direct effect on the reduction. Working with a sufficiently concentrated solution of nitrite, the proportions of the products remain constant throughout the reduction of the nitrite. Probably, this is the case also when an exceedingly dilute solution of nitrite is used, but with a somewhat dilute solution, say one in 30, there is some difference, due to the facts that the presence or absence of much sodium hydroxide modifies the proportion of the products, and that this substance is generated so largely. A dilute solution of sodium nitrite may be made to behave as a concentrated solution in the mode of its reduction by nearly saturating it with sodium hydroxide before bringing it in contact with the sodium amalgam. The addition of sodium hydroxide to a concentrated solution of nitrite before reducing it by sodium amalgam has no sensible effect, for the reason, no doubt, that in the reduction of the nitrite, as it actually occurs, about $3\frac{1}{2}$ mol. sodium hydroxide are produced for one mol. nitrite reduced; quite enough therefore of itself to make the water of a concentrated solution almost proof against the action of sodium. With a large quantity of water present, the sodium hydroxide formed is not enough to render the water inactive, and in this is to be found the explanation of the great difference observed in the proportions of the products, according as the nitrite is dissolved in much or little water.

In order to produce as much *hyponitrite* as possible little

more is necessary than to work with a concentrated solution of the nitrite (1 sodium nitrite to 3 or $3\frac{1}{2}$ water), and add the amalgam in some excess. All else to attend to is that the temperature should not be allowed to rise above 100° , at first, as the yield is a little lowered otherwise. To get as much *hydroxylamine* as possible, the solution of nitrite must be dilute (say 1 in 50) and be kept cold, during the addition of the amalgam. To preserve the hydroxylamine from reduction into ammonia, the solution should throughout be kept well agitated over the amalgam and be poured off from it as soon as nearly all nitrite has been reduced. Much more time is needed to reduce a dilute solution than a concentrated one. The best conditions for producing hydroxylamine, do not allow of much more than half the best yield of hyponitrite being obtained at the same time.

To get much *nitrous oxide* the temperature of the solution must be kept as low as possible, while to get much *nitrogen* the temperature must be kept high. The strength of the solution of nitrite is here without effect, provided that the temperature is properly regulated by external heating or cooling, as may be called for. The reduction of a very dilute solution of sodium nitrite kept very cold, is attended with very little effervescence, because the quantity of nitrogen produced is very small and the nitrous oxide remains dissolved, though ready to escape when the solution is warmed. De Wilde has determined the proportions of gases to each other, but only when the nitrite (or nitrate) was in excess of the sodium. That, however, is sufficient, since qualitative examination of the gases has shown me that variations in the proportions of salt and metal are without sensible influence upon the composition of the gases, and also that this remains apparently unchanged during the progress

of a reduction when the temperature is kept tolerably uniform. De Wilde found that dilute solutions of nitrite or nitrate of sodium or potassium gave larger quantities of nitrous oxide in proportion to nitrogen when the solutions were dilute than when they were concentrated, from which it might seem that strength of solution does affect the proportions of the gases to each other ; but in the experiments conducted by de Wilde, the much greater rise of temperature when concentrated solutions are acted upon fully accounts for the results he obtained.

Ammonia can always be detected from the beginning of the reduction (Thum thought not), but its amount may be minute throughout. It can be got in considerable quantity by using a cold dilute solution, as for producing hydroxylamine, and, after the main action is over, shaking it with amalgam in a stoppered bottle until all hydroxylamine has disappeared. It can also be got somewhat concentrated for a short time by dropping the concentrated solution of the nitrite upon much solid sodium amalgam, as was first observed by de Wilde ; but even then much hyponitrite is still produced. Very hot and dilute solutions of nitrite treated with sodium amalgam give little else than ammonia and nitrogen.

The reduction of potassium nitrite by potassium amalgam is closely like that of the sodium salt by sodium amalgam, in all respects, quantitatively as well as qualitatively.

If, for the moment, nitrogen and hydroxylamine be disregarded, as they well may be, since their proportions become very small under suitable circumstances, the nitrite may then be said to be reduced simply to hyponitrite and much of this to be hydrolysed into nitrous oxide and sodium hydroxide. This at one time I supposed to be the case, and other chemists

have done the same. But, for a long time now, I have felt that most of the nitrous oxide and sodium hydroxide must have another origin. Thum has expressed himself in the same sense, basing his opinion upon the comparative stability of sodium hyponitrite in strongly alkaline solution, in which it can be boiled with only gradual decomposition. This fact by itself, however, is not quite inconsistent with the assumption that the nitrous oxide and sodium hydroxide represent decomposed hyponitrite. But it does not stand alone; there are other facts which tell greatly against the probability of hyponitrite being the source of most of the nitrous oxide obtainable by the reduction of nitrite. (a) Hot concentrated solutions of nitrite yield quite as much hyponitrite as cold ones, unless the temperature is well above 100° , and even then the yield does not fall off much. (b) In all cases the effervescence accompanying the formation of hyponitrite goes on exclusively at the surface of contact with the amalgam. (c) Low production of hyponitrite is not attended with higher production of nitrous oxide. All these facts are opposed to the view that the nitrite is all reduced to hyponitrite in the first place; so, too, is what follows.

The proportions of the products of the reduction of the nitrite vary greatly with the circumstances, but yet only within well-marked limits. Thus, of the nitrite reduced there is from a sixth, under one set of conditions, to almost a fifth, under other conditions, which becomes partly hyponitrite and partly hydroxylamine (and ammonia); while the rest becomes nitrogen and nitrous oxide, one or the other predominating, even largely, according to circumstances. So, too, in one extreme case, nearly all of the one-sixth of the nitrite will change into

hyponitrite, very little becoming hydroxylamine ; or, of nearly one-fifth of the nitrite more than half may be converted into hydroxylamine, only the rest of the fifth becoming hyponitrite, in the other extreme case. It may, therefore, safely be assumed that about one-fifth of the nitrite tends to, or is able to, become hyponitrite, although barely one-sixth of the nitrite can yet be secured as this salt, because either some of this fifth becomes hydroxylamine instead, or, else, that a little hyponitrite is hydrolysed at once or during the process of isolating it. With that assumption to give more precision to the statement, it may be affirmed that many experiments under varied conditions have shown that about a fifth of the nitrite is decomposed by sodium amalgam in one way, and four-fifths in another way ; in one are formed hyponitrite, hydroxylamine, and alkali (with a very little ammonia and nitrous oxide as secondary products), and in the other way, nitrogen, nitrous oxide, and alkali : so that when much hydroxylamine is got it is at the expense of hyponitrite only, and when much nitrogen is got it proves to be at the expense of the nitrous oxide only.

But though this is the case, there seems to be no derivation of the hydroxylamine from the hyponitrite, or of the nitrogen from the nitrous oxide, but, rather, the derivation of the one pair of substances from one transition product and of the other pair from another transition product. It was pointed out in my first paper that sodium amalgam is inactive upon hyponitrite, and this has since been more fully established by Dunstan and Dymond, and again by Thum. According to the last named chemist, hyponitrous acid is not even reduced by zinc and boiling dilute sulphuric acid. I can now assert, in confirmation of my earlier statement, that sodium amalgam has

no action whatever upon a solution of sodium hyponitrite saturated with sodium hydroxide, even when heated to 80° (and no doubt higher), and for days together; no hydroxylamine, ammonia, nitrogen, or hydrogen is produced. In weaker alkaline solutions, hydrogen is very slowly produced, but still without any effect upon the hyponitrite. Weakly alkaline solutions of sodium hyponitrite slowly decompose of themselves, and then some of the nitrous oxide may possibly get reduced by the sodium amalgam, (see p. 31).

As for the nitrogen, it is evident that only while nitrous oxide remains in solution and comes in contact with the amalgam, can it be reduced, even if it is then (see p. 31). Yet, in order to get much nitrogen in place of nitrous oxide, it is necessary to work with hot solutions, when the solubility of nitrous oxide is at its lowest. It is not essential that the nitrite should be in small proportion to the sodium, temperature alone appears to be the condition determining the replacement of nitrous oxide by nitrogen. In other words, weak solutions of nitrite and excess of amalgam in no degree favour the production of nitrogen rather than of nitrous oxide, and nitrogen does not prevail more in the gases escaping near the end of a reduction than near its beginning.

Very different is it with ammonia, truly a product of reduction of hydroxylamine (in non-acid solution), the formation of which takes place principally during the final action of the amalgam. Against the notion, highly improbable as it is, that the nitrogen may come from yet existent nitrite and already formed ammonia, which would also account for the comparative absence of ammonia in the earlier part of the reduction, there may be adduced de Wilde's observation that

ammonium nitrate when reduced by sodium amalgam, gives much more nitrous oxide in proportion to nitrogen than does potassium or sodium nitrate (no doubt because there is less rise in temperature).

Without speculating on the constitution of a nitrite, we are able to see from the interactions between ethyl iodide and silver nitrite that a nitrite may react both as an oxylic salt NaONO and as a halide NaNO_2 . From the sodium reduction there will then first result the radicals NaON= and NaNO . From the former or sodioximido radical may well come the hyponitrite and hydroxylamine, and from the other or sodium nitrosyl radical the nitrous oxide and nitrogen. In accordance with the facts observed, the sodioximide, in concentrated alkaline solution, will condense into sodium hyponitrite, stable against reduction, or, in very dilute alkaline solution, will by hydrolysis and reduction become alkali and hydroxylamine. The hypothetical nitroside will also condense and simply hydrolyse into nitrous oxide and alkali, principally at low temperatures or will become reduced and hydrolysed into nitrogen and alkali, principally at higher temperatures.

To establish the points in the reduction of the two nitrites by their respective metals, here described, I have made very many experiments, usually working upon quarter-gram molecules of nitrite. The hyponitrite obtained was weighed as silver salt. The hydroxylamine was estimated by the quantity of metallic silver it yielded and in this way ;—the black precipitate it causes in silver nitrate solution in presence of alkali, being largely suboxide, this was washed out with cold dilute nitric acid and ammonia alternately, and the residual brownish metallic

silver weighed and calculated into hydroxylamine by the ratio $2\text{Ag}:\text{NH}_3\text{O}$, experiments (described in the next paragraph) with solution of hydroxylamine sulphate of similar dilution and alkalinity having shown me that this could be done correctly enough.

The important observation made by Thum, that hydroxylamine when oxidised by suitably alkalised mercuric oxide, silver oxide, or cupric hydroxide, will yield a little hyponitrite, and nitrite, caused me to ascertain whether in my experiments the destruction of sometimes much hydroxylamine in this way might not contribute some of the hyponitrite afterwards found present. To this end I made a blank experiment, closely similar to those made in studying the reduction of sodium nitrite, except that sodium hyponitrite itself was absent. Thus, hydroxylamine sulphate, 1.5 grams (=0.6 gram hydroxylamine) was dissolved along with 32 grams sodium hydroxide in nearly 2 litres of water and then a solution was run in with stirring, of silver nitrate 7.5 grams, which constituted a good excess, such as was used in the other experiments. The abundant black precipitate was washed and exhausted with ice-cold dilute nitric acid. This solution, neutralised as usual in my other experiments, gave no silver reaction for silver hyponitrite and nothing more than a slow and very slight action upon permanganic acid which might be due to a trace of either nitrous or hyponitrous acid. It was easily seen that some nitrous acid was formed by applying the iodide and starch test. Under the circumstances of my experiments, therefore, even when 7 per cent. of the nitrite had been reduced to hydroxylamine, there will have been no perceptible production of hyponitrite during the after-oxidation of the hydroxylamine. The metallic silver

washed out with dilute nitric acid* and ammonia, weighed 3.8 grams, the calculated quantity being 3.95 grams. The nitrite detected in the mother-liquor of the black precipitate had been formed in too small a quantity to materially affect the weight of the metallic silver.

Generally, sodium hydroxide was approximately estimated, after all hyponitrite had been precipitated, by titration with nitric acid of the mother-liquor and the silver oxide precipitated with the silver hyponitrite and metallic silver. The amalgam used was of approximately known strength ascertained, not by sampling which is impracticable, but by uniformly preparing successive quantities and sacrificing one to assay by dilute sulphuric acid and weighing sodium as sulphate. After use in reducing nitrite, the sodium remaining in the mercury was sometimes similarly determined. Nitrous oxide and nitrogen were not measured—their total nitrogen was found by difference, and their proportions had been sufficiently ascertained by de Wilde, as I have already said—but their relative abundance was estimated by a burning splint of wood, the reduction of the nitrite being always conducted in a loosely closed flask. The range of this reaction was from that of a gas utterly extinguishing combustion to that of one which supported it most vividly; in any uniformly conducted experiment the gases evolved towards the end behaved like those at first given off.

To ascertain the effect upon its reduction by sodium, nega-

* It was proved many years ago that silver is insoluble in dilute nitric acid, the presence of nitrous acid being necessary to make it dissolve. But the contrary has been since asserted to be true where the silver is finely divided, as when precipitated. This error (as I must regard it to be) is due to precipitated silver when black or blackish containing suboxide, which gives it its colour: this is resolved by acid into oxide of silver which dissolves, metallic silver remaining.

tive as this proved to be, of adding sodium hydroxide to a concentrated solution of sodium nitrite I proceeded in two ways. In one the amalgam was covered with a cold saturated solution of sodium hydroxide, which is quite inactive upon it; then the concentrated solution of nitrite was slowly added. At first, the alkali greatly impedes the action of the amalgam upon the nitrite but with more of the solution of the latter added the action goes on faster and to the end and gives the usual large proportion of hyponitrite and very little hydroxylamine. In the other way of testing the point, some concentrated solution of sodium nitrite and sodium hydroxide was treated with some amalgam; then more sodium nitrite was added and then more amalgam. The result was the same as before. My aim in thus working was to have the effects, if any, of the most concentrated alkali from the first, without having to deal afterwards with too inordinate an excess of alkali, when the analysis had to be made.

I have also tried to ascertain the effect of lessening the amount of alkali present. In acid reducing mixtures nitrous acid becomes largely converted into hydroxylamine without production of hyponitrous acid, so that it seems probable that could the alkali formed in reduction of nitrite by sodium be neutralised nearly as fast as produced, much hydroxylamine would be got and very little hyponitrite. The use of the ordinary acids for the purpose in such a way as to give conclusive evidence on the point does not seem to be practicable, while the great rapidity of the process of reduction makes the use of carbon dioxide (Aschan, *Ber.*, 1891, **24**, 1865) very unpromising. I have, therefore, tried the effect of adding ammonium acid carbonate along with the sodium nitrite, expecting the

ammonia to be inactive. In one case I used the amalgam in large excess, which soon gave me much ammonium amalgam, and what was quite unexpected neither hyponitrite nor hydroxylamine. In another experiment in which I kept the nitrite in excess of the amalgam, the previous addition of the ammonium carbonate in excess was without effect; the nitrite solution had to be used slightly dilute because of the carbonate and gave therefore a little less hyponitrite (about 12.7 per cent. of the nitrite consumed) and a little more hydroxylamine (about 3 per cent.) than in the best way of working for hyponitrite. The presence of the ammonium carbonate was therefore without effect, the reaction between the nitrite and the sodium being already complete when the sodium oxide presents itself to the water and ammonium carbonate.

I satisfied myself that a fairly concentrated solution of nitrite is uniformly reduced from beginning to finish, the temperature being preserved tolerably constant, by the simple examination of the gases in the way described and by the following device as regards the hyponitrite and hydroxylamine. A given solution of nitrite received with cooling only half the quantity of sodium amalgam sufficient to reduce it, and was then found to contain hyponitrite and hydroxylamine in the same proportions to each other as if the nitrite had been fully reduced (with cooling) and in tolerably nearly half the quantities the whole nitrite would have yielded.

Sodium amalgam was proved to have little or no action upon nitrous oxide by exposing the gas for a long time to its action. The amalgam was liquid and when shaken up with the moist nitrous oxide in a stoppered bottle coated the sides of the bottle. With occasional vigorous shaking, the bottle was kept

closed four days; when opened it was found to contain the nitrous oxide little if at all deteriorated as a supporter of combustion. In another similar experiment, a saturated solution of sodium hydroxide was poured over the amalgam; in this case the amalgam did not coat the sides of the bottle, but the solution served to keep the nitrous oxide dissolved in contact with the amalgam. The bottle was often vigorously shaken and was not opened till after four days. The nitrous oxide remained almost or quite unchanged. Holt and Sims (*J. Ch. Soc.*, 1894, **65**, 432) have studied the oxidation of sodium and potassium by nitrous oxide, but only at much higher temperatures than those in these experiments, which were 25–30° (hot weather).



Hyponitrites; their properties and their preparation by sodium or potassium.

By

Edward Divers, M. D., D. Sc., F. R. S., Prof.,
Imperial University, Tokyo.

The hyponitrites have received the attention of many chemists besides myself since their discovery in 1871, and even this year new ways of forming them and the new working of an old method have been published. Yet much has been left to be put on record before a fairly correct and full history of these salts can be said to have been given, and the present paper is meant to be the necessary supplement to what has been already published.

Ways of forming hyponitrites.

No writer upon hyponitrites in recent years has shown himself acquainted with all the ways there were then known of getting these salts, or with even the most productive among them. The following complete list is valuable therefore, and is of special interest as bringing together the various ways in which these salts have their origin.

1. Reduction of an alkali nitrite by the amalgam of its metal. (Divers, 1871).

2. Reduction of an alkali nitrite by ferrous hydroxide (Zorn, 1882 ; Dunstan and Dymond).

3. Reduction of (hypo-nitrosulphates by sodium amalgam (Divers and Haga, 1885).

4. Reduction of nitric oxide by alkali stannite (Divers and Haga, 1885).

5. Reduction of nitric oxide by ferrous hydroxide (Dunstan and Dymond, 1887).

6. Decomposition of an oxyamidodisulphonate by alkali (Divers and Haga, 1889).

7. Oxidation of hydroxylamine by sodium hypobromite (Kolotow, 1890).

8. Oxidation of hydroxylamine by mercuric oxide, silver oxide, or cupric hydroxide (Thum, 1893).

9. Interaction of hydroxylamine and nitrous acid (Thum, H. Wislicenus, Paal and Kretschmer, Tanatar, 1893).

10. Oxidation of hydroxylamine by benzenesulphonic chloride and alkali (Piloty, 1896).

11. Interaction, in methyl alcohol, of hydroxylamine and nitrous gases (Kaufmann, 1898, *Ann.*, **299**, 98).

12. Interaction, in methyl alcohol, of hydroxycarbamide and nitrous gases (Hantzsch, 1898).

13. Interaction of dimethylhydroxynitrosocarbamide and alkali (Hantzsch and Sauer, 1898).

Menke's reduction of fused alkali nitrate by iron and Rây's reduction of mercuric nitrite by potassium cyanide in solution are not included in the list, because both reductions are very doubtful and in need of confirmation before they can be accepted as facts. In the present paper only the original method of preparing hyponitrites will be treated of.

**Preparation of sodium hyponitrite solution by reduction
of sodium nitrite by sodium amalgam.**

Sodium nitrite can be converted by sodium amalgam in the easiest and quickest imaginable way into fully one-sixth of its equivalent of sodium hyponitrite, existing in solution and pure but for the presence of much sodium hydroxide. From this solution the sodium salt itself, as well as silver hyponitrite, can be at once prepared nearly pure and with hardly any loss, the presence of much sodium hydroxide being no hindrance. The solution becomes also at once fit for preparing lead, copper, mercury, and some other salts, merely by cautious neutralisation of the hydroxide, which is known to be complete when a little of the solution just ceases to give black oxide when mixed with a drop of dilute solution of mercurous nitrate. Others who have tried this method, and particularly the latest workers, Hantzsch and Kaufmann, have got no such favourable results, these chemists having got only from a third to less than half as much silver hyponitrite as is to be obtained under the best way of working, while D. H. Jackson got with difficulty the sodium salt in quantity too small for investigation.

Pure sodium nitrite is necessary, but that can be prepared very simply, as described in a note contained in this volume, p. 15. In order to get the most hyponitrite and the least hydroxylamine, the nitrite must be in concentrated solution ; three times its weight seems to be the best quantity of water to dissolve it in when evaporation of the water during the reaction is kept down by operating in the way to be just now described, or three-and-a-half times when marked evaporation is caused by allowing greater rise of temperature.

Using such proportions of water, the sodium oxide produced finds about enough to form with itself a solution of the composition, $\text{NaOH}, 3\text{OH}_2$, which, according to my measurements, is a nearly saturated solution of NaOH, OH_2 , at the mean temperature.* In presence of so much hydroxide the water is also quite saturated with hyponitrite, a small quantity of this salt even separating when the solution is kept ice-cold for a time.

To reduce sodium nitrite in cold concentrated solution, $2\frac{1}{2}$ atoms of sodium are found to be needed, the additional half atom being consumed in the unavoidable formation of some nitrogen, hydroxylamine, and ammonia. This accords well enough with the statement in my first paper as a first approximation, that not more than 4 atoms are active upon sodium *nitrate*. In practice, however, 3 atoms of sodium (nitrite and metal, equal weights, therefore) should be used in reducing sodium nitrite, partly because it is wanted afterwards to reduce hydroxylamine, and partly because the reduction of all the nitrite is important, and this can only be accomplished quickly in presence of good excess of sodium. The strength of the amalgam is not an essential point, as regards the nature of its action ; some chemists state the contrary, but as the amalgam and the aqueous solution constitute together a heterogeneous system, I do not see how they can be right. But I have always found it most convenient to prepare and to work with a soft solid amalgam, which is one having the composition, $(\text{NaHg}_{23})_2$, or 23 grams sodium to 1600 grams mercury.***

* Sodium hydroxide forms a saturated solution at 15° in its own weight of water. When cooled, this solution deposits large pointed prisms of the monohydrate.

***Tarnatar erred in supposing that I recommended the use of hard amalgam, and his supposed improvement of my process, like those published by other chemists, is not one in fact.

As with the strength of the amalgam, so it is with the temperature to be maintained during the reduction; it does not much matter if only the solution of nitrite is concentrated, and then no better results can be got than by following my original direction to keep the flask in a stream of cold water during the reduction. The temperature may, in fact, rise nearly to 100° without harm being noticeable, and even by letting the solution boil freely by its own heating up, the temperature then rising to $125-8^{\circ}$, the yield is only reduced by nearly a third. But it is preferable to apply cold externally, particularly in warm weather, by means of a brine-and-ice bath, because then the amalgam can be added much faster, without leading to great evaporation of water. The temperature of the solution during the reduction then ranges, with convenient rate of working, from 5° to 25° . The time taken to add 23 grams of sodium is not more than ten minutes.

From a quarter to a half gram molecule of sodium nitrite is a convenient quantity to work upon, and its solution is best contained in a 350 to 450cc. pyriform, wide-mouthed flask, lying very obliquely in the cooling bath during the addition of the amalgam by aid of a spatula. The last fourth of the amalgam may be put into the flask as rapidly as it can be, and the flask may then be removed from the bath. It is kept actively rotated for ten or fifteen minutes, during which the temperature of its contents will rise to about 40° and then fall. The two liquids are next poured into a stoppered bottle (best, narrow-mouthed) sufficiently capacious to be about half filled by them. The thick aqueous solution adhering to the flask may be washed out into the bottle, but the water should be limited to 2 or 3cc. when the purpose is to obtain afterwards the solid

sodium salt. The two liquids are now violently shaken together for ten minutes or so, when all hydroxylamine will have been destroyed. That it is so may be ascertained by taking out a drop of the solution and adding to it some water, a drop of silver nitrate solution, and slight excess of dilute nitric acid, after which the resulting solution should prove to be free from the least black tint due to silver reduced by hydroxylamine. No gas is liberated during the shaking, but a very strong odour of ammonia is developed. A minute quantity of nitrite is still present, remarkable to say, to remove which altogether seems almost impossible, but which can be so far reduced by an hour's shaking of the solution with the amalgam that a little of the solution largely diluted and acidified does not blue potassium iodide and starch until it has stood for about an hour.

The solution may be separated from the amalgam by a funnel and then be exposed in a dish for a night in a sulphuric acid desiccator; in the morning it will be free from ammonia, and present itself as a virtually pure and stable, concentrated solution of sodium hyponitrite and hydroxide.

As here described, the preparation of a solution of sodium hyponitrite ready for use is the same as that followed by me in 1871, with one important addition and not taking account of the fact that I then had to begin with nitrate and reduce it to nitrite by sodium, as the only convenient way to get the latter salt pure enough. The addition I refer to is the new method of removing the hydroxylamine from the hyponitrite. When silver hyponitrite is prepared from the crude solution, the hydroxylamine gets destroyed by silver oxide, as I pointed out in the addendum to my first paper. Zorn, as an improvement, introduced the use of mercuric oxide, on the ground that

destruction of some silver hyponitrite was thus avoided. In this he was evidently mistaken, having overlooked the fact that it is silver oxide, just as it is mercuric oxide, which becomes decomposed, the hyponitrite or any other acid radical being untouched by the hydroxylamine in alkaline solution. Whether, therefore, mercuric oxide, or silver nitrate, or mercuric nitrate is used and the precipitated metal then separated, the result is just the same in concentrated alkaline solutions, except that the dropping in of a solution of the nitrate is more easy to carry out than stirring up with mercuric oxide. Where the alkaline solution is very weak the use of mercury compounds is not without objection, because in this case a little mercuric oxide remains dissolved. But whether silver or mercury oxide is employed, the result is unsatisfactory; for, as Thum has pointed out, both these oxides generate nitrite in destroying hydroxylamine. Not, however, that Thum himself found this fact to tell against the use of mercuric oxide, for he was apparently successful in purifying silver hyponitrite from nitrite by thorough washing and reprecipitation, and was, therefore, independent of the presence of the produced nitrite. But Berthelot and Ogier, Paal and Kretschmer, and I myself have not had that success, and to get silver hyponitrite free from all trace of nitrite, I have found it necessary to begin by precipitating it in the absence of nitrite. Nevertheless, far from casting doubt upon Thum's success, I hold him to have proved his silver salt to have been some of the purest ever prepared, by the account he has given of the properties of hyponitrous acid. But, after all, no one will be disposed to deny the superiority of sodium to mercuric or silver oxide for removing hydroxylamine from the solution.

An almost pure solution of sodium hyponitrite can be con-

veniently got by dissolving the freshly prepared hydrated solid salt in water. Sodium iodide or potassium iodide and the silver salt will also furnish a solution of alkali hyponitrite. To get a solution for precipitating purposes, Thum proceeded in an indirect way, first preparing a solution of hyponitrous acid and then adding enough sodium hydroxide to make the solution neutral to phenolphthalein, an effective but very wasteful process. Kirschner also wanting a solution for precipitating purposes, used sodium chloride and silver hyponitrite which, in a complex and wasteful way, he made yield a solution that, though mixed with much chloride and nitrate, was practically free from silver.

Sodium hyponitrite.

In 1878 Menke gave full analyses of crystals of a stable salt having the composition of sodium hyponitrite with 6 H_2O in the molecule, which he had prepared by deflagrating in an iron crucible a mixture of sodium nitrate and iron filings, keeping the product at a red heat for an hour in a fire of charcoal rather than of gas, boiling the mass with water, filtering off iron oxide, evaporating, and leaving to crystallise. He makes no reference in his paper to the large amount of sodium hydroxide he must have had to deal with, though this should have seriously affected the procedure. In 1882 Zorn submitted Menke's method to apparently very thorough trial and failed to get the least trace of hyponitrite by it. But he found that ferrous hydroxide acting on a solution of sodium nitrite did produce sodium hyponitrite (in solution). His suggestion that Menke had mistaken carbonate for hyponitrite takes no account of the fact that the nitrogen and water in the salt were repeat-

edly determined. It can now, however, be stated with certainty that Menke's salt was not the sodium hyponitrite obtainable by reducing sodium nitrite by sodium amalgam and water, for this differs from it in degree of hydration and stability and in other properties.

D. H. Jackson (*Proc. Ch. Soc.*, 1893) described two ways in which he had succeeded in preparing sodium hyponitrite, but with such difficulty as deterred him from investigating its properties. Indeed, in proof of his success he mentioned only that he had got crystals and that these contained the proportion of sodium proper to the salt, and this happens to be no proof at all. For, firstly, sodium carbonate has just the same content of sodium, secondly, the hyponitrite is actually a hydrated salt not to be rendered anhydrous without some decomposition, and, thirdly, though of crystalline texture, the salt can hardly be described correctly as occurring in crystals. Nevertheless, his success in getting the salt is not to be doubted. One of the methods he adopted was to reduce a concentrated solution of sodium nitrate by sodium amalgam, evaporate the solution in a vacuum until the salt crystallises, and wash the crystals with alcohol to free them from sodium hydroxide. He found the evaporation to take several weeks and the salt he obtained was very small in quantity. Such should not have been his experience, even though he had taken nitrate instead of nitrite for reduction and thus greatly increased the quantity of sodium hydroxide, very large in any case. With some modification, the process he followed is an excellent one.

To obtain sodium hyponitrite from its solution, prepared as already described (p. 38), is a simple matter, but this solution,

which is of somewhat thick consistence, being generally a little turbid, has to be passed through a Gooch asbestos filter, well covered from the air. It consists of one molecule of sodium hydroxide to only 3 mols. water and is just saturated with hydrated sodium hydroxide, while there are about $21\frac{1}{2}$ atoms of sodium present as hydroxide to one present as hyponitrite. Cooling alone will cause some of the hyponitrite to separate and the solution readily loses water in a vacuum over sulphuric acid until it retains only about 2 molecules to one mol. sodium hydroxide, when almost all sodium hyponitrite will have separated out. At a temperature of $25-30^{\circ}$ this will happen in about 40 hours, the salt separating as minute crystalline, round granules, some scattered over and adhering to the walls of the dish but most of them united into a thick crust on the surface of the solution. Below 15° the mother liquor readily deposits crystals of the monohydrate of sodium hydroxide. As also evaporation is slower in the cold, it is better for both reasons to evaporate in a warm room.

The only effective way of separating the salt from its viscid mother-liquor is by the pump and a Gooch crucible unlined with asbestos; draining on the tile is impossible. By the same apparatus it is washed with absolute alcohol and then transferred to a basin and gently rubbed up with fresh portions of alcohol, till all sodium hydroxide has been removed. Drained now on a good tile it is for the time being nearly the pure hydrated salt, very unstable, losing both water and nitrous oxide, and consequently acquiring sodium hydroxide again. But, placed promptly in a vacuum desiccator, it becomes anhydrous before it has very much decomposed and is then quite stable in dry air. The amount of the hydrated sodium hyponitrite should be

quite one-sixth of the calculated quantity, and the mother-liquor be left too poor in hyponitrite to be worth working up as a source of silver hyponitrite.

A modification of the method, which is equally successful as to yield, is to dispense with the evaporation of the water and precipitate the salt by absolute alcohol. The only precaution to be taken is to hinder as much as possible the salt getting attached to the walls of the vessel, and this for obvious reasons. Very much alcohol is required, because of the very large proportion of sodium hydroxide which is present. A few drops of the solution are added to the alcohol in a flask and at once violently shaken with it until thorough solidification of the hyponitrite has occurred; then gradually the rest of the solution is poured in with good agitation. With abundance of alcohol from the first and with good mixing, very little of the salt will remain in solution and very little adhere to the flask; with less alcohol at first, a material quantity of the salt is lost by being kept in solution, for, though it is afterwards slowly deposited, it is not then in a serviceable condition, and much salt is liable to adhere to the flask, which can, indeed, be dissolved out in water and be reprecipitated by alcohol, but only with very great loss.

The action of sodium chloride upon silver hyponitrite, which will be described along with the other reactions of silver hyponitrite (p. 52), is complex and quite unfit to furnish a simple solution of sodium hyponitrite. Nevertheless the solution obtainable by this action, charged as it is with sodium chloride and containing, besides, some silver hyponitrite dissolved in it, can be made to deposit its sodium hyponitrite by mixing it with much absolute alcohol, and this constitutes Jackson's second

method of getting the salt. As thus obtained, however, it always has a little chloride mixed with it, and will hardly therefore, be serviceable for any of its purposes.

The granular form of sodium hyponitrite is best marked in it when it has separated from a highly concentrated solution of sodium hydroxide ; when it is redissolved in a very little water and this is rapidly evaporated in an exhausted desiccator, the salt separates as an almost structureless membrane on the surface and there readily becomes opaque and apparently anhydrous. In the ordinary desiccator a finely granulated crust forms. I have never got crystals. The salt, quite freshly prepared, has an exceedingly mild alkaline taste.

No very satisfactory results have been got in attempts to determine the degree of hydration of the salt, because of its instability, but they point to the formula, $(\text{NaON})_2(\text{OH}_2)_6$. That formula requires for the sodium the number 23.47 per cent., while analysis of the salt, weighed as soon as it was almost free from alcohol, gave 23.66 per cent. In place of 30.61 per cent. for the hyponitrite ion, 28.10 per cent. was obtained by dissolving the salt in water and precipitating with silver nitrate, a deficiency fairly attributable to decomposition before the silver nitrate could be added ; for, as proved by Zorn, this way of estimating hyponitrous acid is accurate. Loss of weight in the vacuum desiccator gave 44.91 per cent., while the calculated quantity of water is 45.92 per cent., but the difference is easily accounted for as due to loss of nitrous oxide, and, indeed, would be even greater but for the fact that this loss involves fixation of water by sodium oxide.

The anhydrous salt, somewhat decomposed, is non-coherent and opaque, and in appearance much like *magnesia alba*. It

evolves heat in dissolving in water, and is insoluble in alcohol. It only slowly takes water from a solution of itself. Heated in a closely covered vessel it yields nitrogen and sodium oxide mixed with some nitrite :— $3(\text{NaON})_2 = 2\text{N}_2 + 2\text{Na}_2\text{O} + 2\text{NaNO}_2$. The salt bears a heat of 300° without decomposing, and then melts and effervesces ; glass, platinum, and even silver are freely attacked by the fused mass. The mass hisses when water is added to it. Sodium hydroxide and nitrite are the solid products when the hydrated salt is quickly heated, and nitrous oxide, as well as nitrogen, is given off. Strong sulphuric acid decomposes the salt, with production of odourless white vapours and does not form nitrosyl sulphate, when the sodium salt is pure enough.

The salt or a fairly concentrated solution of it effervesces with a dilute acid like a carbonate. The solution precipitates calcium and most other hyponitrites at once from the respective reagents. It dissolves a little silver hyponitrite and decomposes silver chloride (see the account of silver hyponitrite, p. 50). Dry sodium hyponitrite is not decomposed by carbon dioxide and, since the hydrated or dissolved salt partly decomposes by interaction with the water, its power of fixing carbon dioxide does not indicate that it is directly decomposable by that substance. The solution decomposes moderately fast, when boiled, into hydroxide and nitrous oxide. Allowed to stand for a day it develops in itself a trace of nitrite.

Potassium hyponitrite ; potassium amalgam.

The preparation of a solution of potassium hyponitrite is throughout like that of a solution of the sodium salt. It is

only necessary therefore, to say something concerning the potassium amalgam which is required, and of which as a reagent little or nothing has been published.

Merely for convenience in working, the composition of the potassium amalgam should correspond pretty closely, in parts by weight, to that recommended for the sodium amalgam, namely, $(\text{Hg}_{14}\text{K})_2$, or 2800 mercury to 39 potassium, this being the weakest amalgam that is solid, and a pasty amalgam like that of sodium not being obtainable. Although it crystallises in simple cubes, often very large, which are so sharp angled that they can hardly be introduced into a flask without fracturing it, the crystals are very easily crushed in a porcelain mortar and are then in a state quite convenient for use. Sodium or potassium amalgam not stronger than here recommended (1 kg. mercury to 14 grams alkali metal), is particularly easy to prepare in Draper's way, that is, melting the sodium or potassium under paraffin wax and adding the mercury to it, at first very gradually. The operation can be performed on the open table. When cold and wanted, the amalgam is uncovered by cutting through and lifting off the cake of paraffin and dug out with a spatula. In spite of the fact that more heat is evolved, according to Berthelot's numbers, the formation of potassium amalgam is less violent than that of sodium amalgam. Potassium, also, nearly always requires to be well stirred with a glass rod to bring about its first contact with the mercury under the paraffin;* sodium never does. When all the mercury has been added, either amalgam requires good stirring in order to dis-

* Probably only because the potassium presses so lightly upon the mercury on account of its specific gravity not much exceeding that of the paraffin, and not because of any chemical difference.

solve up all lumps and should again be stirred when solidifying, in order to disturb crystallisation as much as possible. The specific gravity of paraffin wax is about the same as that of potassium, but paraffin expands so very greatly in melting that the potassium readily sinks in it when it is in the liquid state. Muhlhaeuser, many years ago, melted sodium under petroleum and then added the mercury to it, and, in recent years, Nef has recommended the use of toluene, which boils freely by the heat of the union of the metals. But toluene could hardly be used in making potassium amalgam, because of its specific gravity.

A highly concentrated solution of potassium hyponitrite and hydroxide having been prepared, the hyponitrite can be precipitated by absolute alcohol, but only very incompletely and some of what is precipitated is afterwards dissolved away in washing it with more alcohol. The preparation of this salt is therefore less satisfactory than that of the sodium salt.

Another way of making potassium hyponitrite is to decompose silver hyponitrite with exactly the right quantity of solution of potassium iodide. By rapid evaporation under reduced pressure the solution can be concentrated, as preparation for treating it with absolute alcohol, though with partial decomposition of the salt, and can even be dried up, so as to yield the impure solid salt. The cold of evaporation in a vacuum has sometimes caused the separation from the concentrated solution of hydrated crystals which, however, melt when placed on filter paper; otherwise, the salt is obtained anhydrous in minute prismatic crystals. The salt decomposes more rapidly than the sodium salt, but is stable when quite dry. It is soluble in 90 per cent. spirit, and slightly even in absolute alcohol. Its aqueous or alcoholic solution yields silver hyponitrite with sil-

ver nitrate, dissolves silver hyponitrite to some extent, and in other respects behaves like one of sodium hyponitrite. It has not been obtained sufficiently undecomposed to be fit for quantitative analysis.

Preparation of silver hyponitrite.

The hyponitrites were discovered through the production of the silver salt and since that discovery this hyponitrite has been prepared and redescribed by many chemists. But no deviation from the first account of it by myself occurs in the later descriptions that is correct, while the only additions made to it are that the salt can of course be obtained in a purer state than I at first got it and that it gives when heated some nitric peroxide. The very poor success in getting it in satisfactory quantity in recent years is remarkable (see p. 35). It has been due to erroneous procedure, partly in reducing the nitrite and partly in converting the sodium hyponitrite into the silver salt.

The concentrated solution of sodium hyponitrite and hydroxide, already described (p. 38), is to be mixed with just sufficient silver sulphate or silver nitrate, in presence of much water, for the sodium hydroxide is not to be neutralised but only to be largely diluted. (Neutralisation can, indeed, precede precipitation, if desired, as in preparing mercury and other hyponitrites, but it is here quite unnecessary and risks the loss of some hyponitrite). Silver sulphate is to be used as the precipitant where it is essential to exclude nitrate from the silver hyponitrite ; for, as will be shown, washing and reprecipitating are usually imperfect means of purifying the precipitate.

Supposing a half gram molecule of sodium nitrite to have

been reduced, the alkaline solution, diluted to three times its volume or more, is mixed with 13 grams silver sulphate or 14 grams silver nitrate dissolved in about 3 litres water, and the mixture stirred vigorously at once and continuously for five minutes, in order to convert the silver oxide into silver hyp-nitrite. After subsidence of nearly all the precipitate, the turbid liquor, if bright yellow rather than brownish, is decanted and more silver solution added to it until, after good stirring, some brown silver oxide remains, when the whole is poured back and stirred up with the main precipitate and then left to settle. Good daylight is almost essential for judging the colour of the precipitate when finishing, but no more exposure of the precipitate to light than necessary should be permitted.

After some washing by decantation the precipitate is stirred up with successive portions of highly dilute sulphuric acid (3 or 4 per mille) until this fails to get fully neutralised and shows, therefore, when poured off and mixed with a drop of sodium carbonate, a slight yellow opalescence of silver hyp-nitrite. The precipitate is washed with water by decantation till it gives up no sulphate, stirred up with water containing a trace of sodium carbonate, and finally again washed with water. It is collected on a filter and dried in the dark in a vacuum. When thus dried it may be heated for a time to 100° in dry air without harm and become still drier. It is now often as pure as it can be got. Not always, however, are the operations so perfectly carried out as to ensure this degree of purity, and it is, therefore, sometimes desirable to submit the salt to further treatment, preferably before it has been dried. In that case it is dissolved, in portions at a time, in 3-per-mille, ice-cold sulphuric acid and is either expedi-

tiously filtered, if necessary, into some sodium carbonate solution or, if not, is at once made alkaline with sodium carbonate. The reprecipitated salt is then treated with sulphuric acid and washed, all just as was done with the original precipitate. Even after reprecipitation, the silver hyponitrite coming from 34.5 grams sodium nitrite will weigh about 11 grams.

The way of preparing silver hyponitrite just given differs from that contained in my first paper in not neutralising the sodium hydroxide with acetic acid, in taking silver sulphate instead of nitrate, sulphuric acid in place of nitric acid, and sodium carbonate in place of ammonia, and in some minor details. The use of sulphuric acid is not new, that acid having been first used by van der Plaats, but the motive for the change is new and has been already given (p. 48). Cold dilute sulphuric acid is not in the least less active than nitric acid in decomposing silver hyponitrite; in fact, unless very dilute, it is more active in consequence of silver sulphate crystallising out. Sodium carbonate (used by Haga and me in 1884, *J. Ch. Soc.*, **45**, 78) is to be preferred to ammonia for precipitating the salt as being more sensitive, and because the last trace of ammonia is difficult to wash out of the silver salt (as Hantzsch and Kaufmann have found to their cost—see p. 64). It is easy to ensure absence of all silver carbonate along with complete precipitation of the hyponitrite, because of the solubility of the carbonate in the carbon dioxide always present in the solution.

Properties of silver hyponitrite.

Silver hyponitrite is bright yellow, and when pale in colour it generally contains a trace of ammonia or loosely combined

silver oxide. If along with such impurity there is also black silver suboxide, the colour becomes dull greyish yellow, but when other impurities are absent, the presence of a little black oxide renders it somewhat bright green, as seen principally in the crude salt prepared by the oxyamidosulphonate method. The difference of colour observed has even suggested the possibility of the existence of different modifications, but there is really nothing to support the notion.

Precipitated from strongly alkaline solution, or from concentrated solutions of the sodium salt and silver nitrate, or on rubbing the calcium salt with strong solution of silver nitrate, silver hyponitrite is dense; but precipitated from its dilute acid solution by neutralising, it is flocculent and bulky. When deposited from its ammoniacal solution through evaporation or large dilution with water it is crystalline (Kirschner; but see also Paal and Kretschmer).

It is slightly more soluble in water than silver chloride, soluble in well diluted nitric acid and sulphuric acid, so as to be recoverable from its solution by quickly neutralising the acid. The quantity of nitric acid required to dissolve it is considerable, being about 3 equivalents. The sulphuric acid solution very soon deposits silver sulphate. Acetic acid dissolves it only very slightly in the cold; phosphoric acid dissolves it but not very freely. It is dissolved by ammonia solution but only sparingly when this is very dilute, and can be recovered either by neutralising or dissipating the ammonia. It is also soluble in ammonium carbonate solution and very slightly in ammonium nitrate solution. Of particular interest is its solubility to a slight extent in hyponitrous acid solution and to a greater degree in solution of an alkali hyponitrite.

It is readily oxidised by strong nitric acid. Strong sulphuric acid acts energetically, the heat of reaction being itself quite sufficient to decompose some of the salt, a fact which accounts for the production of some nitric peroxide and nitrosyl sulphate (see effects of heating, this vol., p. 54). It is not decomposed by a cold solution of sodium carbonate or by one of sodium hydroxide if it is weak. It is fully decomposed by its equivalent of potassium iodide in solution, but only imperfectly by a solution of sodium chloride used not in good excess. When a solution of sodium chloride is shaken with excess of undried silver hyponitrite, decomposition ceases when the two sodium salts in the solution are in the proportion of 18eq. chloride to 25eq. hyponitrite, or by weight, 4 chloride to 5 anhydrous hyponitrite. Absolute alcohol in large excess effects a partial separation of the two sodium salts, as already described (p. 43).

Silver hyponitrite in the moist state is not entirely stable, decomposing even at the common temperature, though exceedingly slowly, light and heat quickening the change and the former modifying it to some extent. The decomposition is made evident by the salt losing its brightness of colour, by its answering to the iodide and starch test for a nitrite, and by its yielding up to water more silver salt (not nitrite, apparently nitrate) than its own very slight solubility accounts for. The salt may be washed with boiling water, or even be boiled with water without very apparent result, but continuous boiling not only has marked effect in decomposing it but an action which grows in intensity, even though the water is frequently replaced. The water comes to contain material quantities of silver nitrate, while the solid salt gives the reaction for nitrite. Masses of

moist precipitate retain their colour outside while drying in a thermostat, but become greyish inside. Silver hyponitrite dissolved in solution of sodium or potassium hyponitrite decomposes on standing and very quickly on boiling, silver being reduced and sodium nitrite formed in solution.

Bright diffused light causes enough change in a few hours—bright sunlight in a few minutes—to allow of nitrite being detected. The colour change caused by light has been variously described ; as a matter of fact, in the sufficiently pure salt under water, it is such that the bright yellow hyponitrite becomes covered with a somewhat bright brown flocculent substance, closely like silver oxide which perhaps it is; the blackening or greying which has been observed by others to be caused by light must have been due to impurities, though time, as just described, brings about greying of the salt. Silver hyponitrite is least sensitive to light when dry and exposed to dry air. The main change which occurs in the moist salt, slight as it is, is evidently similar to that which heat causes. The salt prepared by the oxyamidodisulphonate method generally shows an unreal stability, due apparently to presence in it of a trace of sulphite, as will be explained when the properties of a hyponitrous acid solution are being treated of (p. 63). For in that connexion it has to be taken into consideration that, like many other precipitated substances, silver hyponitrite is difficult to obtain of high purity. The very slight atmospheric oxidation of moist silver hyponitrite, described by Haga and me (*J. Ch. Soc.*, 1884), I now regard as being not the oxidation of the salt itself, but of nitric oxide produced by the very slowly decomposing salt, which is then retained as nitrate and nitrite in the salt. The result will be the same as if the salt itself oxidised.

Effects of heating silver hyponitrite.

In my first paper it is stated that silver hyponitrite is decomposed by a moderate heat into nitric oxide, metallic silver, and a little silver nitrate—in this respect resembling silver nitrite, and that it does not fuse or exhibit any other change except that from a bright yellow to a silver-white colour. That is still a correct statement, so far as it goes, but it is imperfect. In 1887 van der Plaats stated that silver hyponitrite decomposes explosively when heated; presumably his preparation contained acetate. Thum, who properly denied its explosive character in 1893, observed that in decomposing by heat, the bright yellow salt becomes dark brown before assuming the white colour of silver, while Kirschner found (1898) that the salt becomes temporarily black. Thum's observation was due, I think, to the very dense red, almost opaque, hot nitric peroxide which then pours forth and through which at times the solid mass does look very dark. Kirschner's observation may be due also to this cause or to his hyponitrite having contained sulphite. However this may be, the salt decomposes with only the change of colour I have described and in a lump of the precipitate the change can be followed by movement of the sharp boundary line between the bright yellow salt and bright white metal, just as it can be followed in calcium oxalate decomposing by heat; there is no brown or black intermediate stage. Thum seems to have found no silver nitrate, but observed the production of dense red fumes even when the salt was heated in an atmosphere of carbon dioxide and at a temperature not much(?) above 100°. From the important observation of the generation of nitric peroxide he concluded that the decomposition of silver hyponitrite

by heat is probably into silver, nitrogen, and nitric peroxide. I had of course seen in my early work, the production of red fumes but had attributed this to the nitric oxide meeting the air, and to the decomposition at a higher temperature of the silver nitrate which had been formed. The further study of the decomposition which I have made has proved that always there are produced metallic silver, silver nitrate, nitric peroxide, nitric oxide, nitrogen, and possibly a trace of nitrite.

Having assured myself that nitric peroxide, as well as nitric oxide, is evolved by silver hyponitrite when heated, I exposed some to heat in a rapid current of carbon dioxide in order to sweep away as fast as I could, the nitric peroxide that was produced. For the production of nitric peroxide may sufficiently account for that of silver nitrate secondarily. The nitric peroxide and the metallic silver should give the nitrate (Divers and Shimidzu, *J. Ch. Soc.*, 1885, **47**, 630) but it seems improbable that these two substances being produced would then immediately interact at the same temperature. There is however, no reason why the nitric peroxide of the decomposed part of the salt should not act upon the undecomposed part of it and thus produce nitrate, such interaction readily taking place. My experiment recorded above was instituted to see whether I could not almost prevent the formation of nitrate. The attempt failed, for I found as much as $\frac{1}{17}$ of the total silver as silver nitrate in the residue. But this result does not disprove that the nitrate really is formed in the way suggested.

The nature and composition of the gaseous products were ascertained by heating the salt in a vacuum. The quantity of salt taken was in each experiment so proportioned to the capacity of the little flask or bulb in which it was heated as that

the volume of the gases at the common temperature and pressure should be a little less than the capacity of the bulb. The air was removed from the bulb holding the salt by means of the mercury pump while the bulb was kept in boiling water to ensure the dryness of the salt. When evacuated of air, the bulb was sealed off and the silver hyponitrite decomposed by heating the bulb in a bath and not by the naked flame. Thus heated in the absence of air and moisture, the salt exhibits scarcely any change below 140° and only slow decomposition between 140° and 160° , but above these temperatures the change is soon complete. The metallic silver is slightly caked together, presumably by the silver nitrate, and the gases are faintly red between 140° and 150° and orange red at 160° and above. On allowing the vessel to cool, the gases become colourless but regain their colour just as before when the vessel is again heated, and these changes can be repeated any number of times.

To examine the contents of the bulb when cold, its point was broken off under water and the small rise of water into the neck of the bulb marked; then the bulb was transferred to a small trough of strong solution of sodium sulphite in order to absorb the nitric oxide (this vol., p. 10). After an hour or longer the residual gas was examined and measured, by bringing the bulb mouth upwards, testing the gas as to odour and power to support combustion, and then filling it with water from a burette up to the mark already made and to the mouth, in order to learn the volumes of the gases when corrected for temperature and pressure. The volumes could be only approximately measured in this way, but quite well enough for the purpose. The metallic silver was weighed, and from its weight

and that of the hyponitrite, that of the silver nitrate became known. In one experiment the bulb was at once freely opened to the air and the gases rapidly blown out; in this way the nitric oxide showed its presence by reddening in the air and both the silver and the silver nitrate were directly determined.

These experiments established the production of nitrogen, as well as that of the other substances and the non-production of any appreciable quantity of nitrous oxide. The quantitative results were that when the decomposition is slowly effected, as between 140° and 160° , silver hyponitrite yields about 27 per cent. of its nitrogen in the free state and about 20 per cent. when the decomposition is rapidly accomplished at higher temperatures. The silver nitrate was found in quantities corresponding with those of the nitrogen, according to the equation— $3(\text{AgON})_2 = 4\text{Ag} + 2\text{AgNO}_3 + 2\text{N}_2$; but that of course proved nothing, since the whole of the nitrate might have been formed by the nitric peroxide during the cooling, as certainly much of it must have been. On the other hand, the limited quantities of nitrogen generated gives full proof that much nitric oxide is either primarily formed or comes from interaction between hyponitrite and peroxide, besides what undoubtedly comes from the interaction of the nitric peroxide and metallic silver during the cooling. Were none of the nitrogen of the salt to become nitric oxide, the free nitrogen would be half of the total nitrogen, instead of only three or four fifteenths as found.

From the facts observed it seems to me to be highly probable that silver hyponitrite decomposes into silver, nitrogen, and nitric peroxide, according to the equation— $2(\text{AgON})_2 = 4\text{Ag} + \text{N}_2 + 2\text{NO}_2$, and that interaction then occurs between yet undecomposed hyponitrite and some of the nitric peroxide, thus:—

$(\text{AgON})_2 + 4\text{NO}_2 = 2\text{AgNO}_3 + 4\text{NO}$, and, therefore, that the decomposition of silver hyponitrite into silver and nitric oxide does not directly occur.

It remains to explain the absorption and regeneration of nitric peroxide by cooling and heating the gases in contact with the solid residue of the decomposed hyponitrite. The interaction of silver and nitric peroxide in the cold, already referred to, explains the disappearance of the nitric peroxide, half of its nitrogen becoming nitrate and half nitric oxide. The regeneration of nitric peroxide at such low temperatures as those in the neighbourhood of 150° is explained by experiments of mine recorded in a separate note (this vol., p. 11). The silver nitrate and nitric oxide interact to produce nitric peroxide and at first nitrite but ultimately silver itself :— $\text{AgNO}_3 + \text{NO} = \text{Ag} + 2\text{NO}_2$.

**As to the existence of the silver nitrito-hyponitrite,
nitrate-hyponitrite, and nitrate-nitrite.**

Silver nitrate-nitrite.—I have made new experiments upon the union of silver nitrate with silver nitrite, first examined by me in 1871 (*J. Ch. Soc.*, **24**, 85). Silver nitrite mixed with a little less than its equivalent of silver nitrate suffers only slight decomposition until it melts along with the nitrate at about 130° . The fused salts solidify at about 125° to a translucent, greenish-yellow, crystalline mass, except in the uppermost part, where it is opaque from the presence of bubbles and metallic silver. This upper part removed, the rest can be fused again without suffering further change and even be heated nearly to 180° without decomposing. Silver nitrite heated alone shows marked change of colour when the temperature has reached 120° , gives red fumes at about 140° , and very freely decomposes below

180° without showing signs of fusing. Silver nitrate does not fuse below 217° (Carnelley). The low melting point of the mixture of the two salts and the increased stability of the nitrite are, however, the only facts showing that there is some chemical union, for water separates the two salts.

Nitrato-hyponitrite non-existent.—Silver hyponitrite (4 pts.) and silver nitrate (5 pts.) in intimate mixture were heated in a bath. No change was distinctly observed till 175° was reached, when fusion and the evolution of red fumes occurred. The hyponitrite had then disappeared and the fusion may be attributed to the decomposition of the hyponitrite as usual into nitric oxide among other things and to the interaction of this nitric oxide with some of the nitrate to form the fusible nitrato-nitrite.

The attempt was also made to prepare a compound of the two salts in presence of water, there being some grounds to expect success. Calcium hyponitrite, a nearly insoluble salt, was ground up with excess of a very concentrated solution of silver nitrate and a dense and strongly yellow precipitate obtained, which was washed with water till calcium salt had been all removed. The precipitate was still yielding up a little silver nitrate when the washing was stopped. Drained on a tile and dried in a vacuum, it proved to be somewhat sensitive to light and to heat, but as it contained 76.94 per cent. of silver and could have been washed more free from silver nitrate, combination of the two salts stable in water does not exist. Only can it be said that silver hyponitrite requires long washing to separate the last portions of silver nitrate from it.

Nitrito-hyponitrite also non-existent.—In a paper, already referred to, I have recorded getting a minute quantity of what

appeared to be hyponitrite when partially decomposing silver nitrite by heat, that is, a bright yellow substance insoluble in water and soluble in ammonia. I have failed to get this again. Silver hyponitrite and silver nitrite heated together show nothing until decomposition and the escape of red fumes occur, and then all hyponitrite has been destroyed.

When making known his observation of the interaction of hydroxylamine and nitrous acid in 1893, Paal stated that from a solution of alkali hyponitrite which also contained nitrite, silver nitrate had precipitated a substance which, though like silver hyponitrite, proved to be a silver nitrito-hyponitrite. It gave no silver nitrite even to hot water, and could be dissolved in cold dilute nitric acid and be reprecipitated with ammonia without suffering change in composition. It was less stable than the simple hyponitrite when heated, gave the reactions of a nitrite along with those of a hyponitrite, and yielded numbers (not quoted) on analysis for silver which agreed nearly with that required by the formula, $\text{Ag}_2\text{N}_2\text{O}_3$. Ten years before, Berthelot and Ogier, under probably similar conditions, had got similar results, except that they were led by their analyses to give the formula, $\text{Ag}_4\text{N}_4\text{O}_5$, to the substance they had obtained. It is true that silver hyponitrite retains with obstinacy enough nitrite against endeavours to purify it, to give the iodide and starch reaction for a nitrite, and that it often, through the presence of impurities which escape attention, gives low results for the silver, but beyond these admissions I cannot subscribe to the accounts given by the chemists just named of the existence of compounds of silver hyponitrite with silver nitrite.

I have reduced sodium nitrite by sodium amalgam, as usual, and dissolved in the solution one-sixth as much more sodium

nitrite as had been reduced, thus getting hyponitrite and nitrite together in solution in about equivalent proportions, in accordance with the experience recorded in this paper. The precipitation of silver hyponitrite was then proceeded with, in one experiment, without previous neutralisation of sodium hydroxide, and in another experiment only after neutralisation of the alkali. The result was the same in the two experiments. There was a bright yellow precipitate, not noticeably different from ordinary hyponitrite, and the mother-liquor retained much alkali nitrite or silver nitrite in the respective cases. The precipitate was repeatedly washed with cold water, but the washing was stopped when very little silver was being extracted. It proved to be somewhat sensitive to light and heat. It was dried in the cold and in a vacuum and then had its silver determined. This was 76.9 per cent. Nitrite could be easily detected in it, but the compound, $\text{Ag}_2\text{N}_2\text{O}_3$, would have only 74 per cent. silver and $\text{Ag}_3\text{N}_4\text{O}_5$ only 76 per cent. Besides this, by prolonged washing the hyponitrite can be made much purer. There is, therefore, no evidence to be got from these experiments of the existence of such a compound as Paal has described.

Properties of a solution of hyponitrous acid.

Solutions of hyponitrous acid are always prepared in one way, that of decomposing silver hyponitrite with just sufficient dilute hydrochloric acid. Hyponitrous acid has been obtained by Hantzsch and Kaufmann in crystals very deliquescent and unstable, by replacing water by dry ether in its preparation. The acid in dilute solution reddens litmus not so strongly as nitric acid but much more than carbonic acid. On drying the

reddened litmus paper it becomes blue again. A solution of the acid becomes neutral to litmus when only half enough baryta water or alkali to form the normal salt has been added (Zorn). Such a solution soon by decomposition acquires the property of blueing red litmus paper. When neutral to litmus the solution is also neutral to phenolphthalein (Thum). Neutralised with baryta, hyponitrous acid yields an acid salt when its solution is very rapidly evaporated under reduced pressure, crystalline and extremely unstable (Zorn).

It decomposes silver carbonate, if not also lead and other carbonates ; it also decomposes silver nitrate and sulphate. It does not oxidise hydrogen iodide (iodide and starch reagent) and is not oxidised by iodine solution or by the air. It is oxidised by nitrous acid and the stronger oxidising agents. No way of deoxidising or hydrogenising hyponitrous acid is known ; it entirely resists the action of sodium amalgam and also, according to Thum, that of zinc and sulphuric acid. Ethyl hyponitrite is reduced apparently by tin and acetic or hydrochloric acid to alcohol and nitrogen, according to Zorn, but as, also according to him, it is slowly decomposed by itself when moist into nitrogen, alcohol, and aldehyde, there is sufficient reason to doubt that this reduction by tin and acid is more than the hydrogenisation of aldehyde.

Hyponitrous acid slowly decomposes into nitrous oxide and water. A strong solution soon effervesces, gently in the cold, freely when heated, just like a solution of carbon dioxide, and some hyponitrites in presence of only a little water effervesce with an acid. A solution of one or two grams of the acid in a litre of water kept in ice hardly falls noticeably in strength in one hour, but at 25–30° it may lose a sixth of the acid by

decomposition in 24 hours. At a lower temperature, Thum observed a loss only half as great in the same time. Hyponitrous acid solution dissolves silver hyponitrite slightly. The alkali salts of hyponitrous acid dissolve silver hyponitrite somewhat more freely, and also decompose silver chloride (see pp. 45, 52); they also give precipitates with barium and calcium salts and with solutions of most metallic salts. Alkali hyponitrites in solution also decompose into nitrous oxide and alkali, gradually in the cold and rapidly when heated; alkali hydroxides impede the decomposition and when highly concentrated stop it apparently altogether (see p. 38); neutralisation of the alkali, even by carbonic acid, hastens the decomposition as a matter of course, but there is no evidence that carbonic acid is able to decompose a hyponitrite, as it has been stated to be.

Other substances are liable to be present in the solution of hyponitrous acid, and this fact has caused the properties of the acid to be certainly in some points wrongly described. In one point it was so by me in my first paper, in which, however, was contained the warning that the crude solution of the acid, which had been examined, might have reacted as it did, partly through the presence of other unrecognised substances in it. That solution decolourised iodine water and prevented the action of nitrous acid on an iodide; but this was not by the hyponitrous acid in it but by a very little hydroxylamine then unrecognised. Kirschner has again given to hyponitrous acid the property of decolourising iodine water to a slight extent. In his case the substance active upon the iodine will have been a trace of sulphur dioxide; for he made his solution of the acid from silver hyponitrite that had been prepared by the oxyamidodisulphonate method. I can confirm

the accuracy of his observation. Even when the silver hyponitrite has been most carefully precipitated, so as to avoid all sensible precipitation of sulphite, and has been dissolved in dilute acid and reprecipitated, it has still given a solution of hyponitrous acid active upon a very little iodine water. But then, though the hyponitrous acid remained in solution, iodine was not further taken up, while the acid prepared from silver hyponitrite not derived from oxyamidosulphonate, does not decolourise iodine at all, as Thum first pointed out.

Hyponitrous acid, according to van der Plaats, liberates iodine from potassium iodide ; according to Thum and my first paper, it does not ; while, according to Hantzsch and Kaufmann, it only does not do so just at first. The last named chemists, therefore, state that the acid does not itself liberate iodine but quickly begins to yield nitrous acid which does liberate it. They also found hyponitrous acid to yield ammonia, but in a later publication, Hantzsch and Sauer state that the ammonia was an impurity in the silver hyponitrite which had furnished the acid. Even with the simultaneous formation of the ammonia, it is difficult to understand the generation of nitrous acid. These authors, invoking the aid of tautomerism, suppose that the hydrogen leaves oxygen for nitrogen, giving the unknown substance, $\text{HN}:\text{O}$, which then becomes $\text{NH}_3 + \text{N}_2\text{O}_3$, and these, again, pass into $\text{HNO}_2 + \text{N}_2 + \text{OH}_2$. In place of this series of improbable—I would say, unnatural—changes, I suggest that, if indeed such change occurs at all, it must be into water, nitric oxide, and nitrogen, the nitric oxide then oxidising into nitrous acid. But I am strongly disposed to deny that hyponitrous acid decomposes of itself into anything but what are certainly its main products, nitrous oxide and water. My reasons are several.

First, there is the unlikelihood that the diazo radical, $N:N$, should resolve itself into mono-nitrogen compounds, such as NO , NH_3 , $NO.OH$, or $(NO)_2O$, instead of $(N_2)O$. Secondly, there is the fact that time comes in as the condition of the production of nitrous acid, and that a rise in temperature does not. Solution of hyponitrous acid of fair purity boiled or quickly evaporated gives only nitrous oxide and water; and only very slowly and slightly does nitrous acid appear in a cold solution of the purest acid. Thirdly, the more care taken to reduce and exclude all nitrite in preparing the hyponitrous acid solution, the longer will be the time before a sensible quantity of nitrous acid develops and then the more gradually will its quantity increase, from which facts the almost necessary inference is that never has quite all nitrite been removed and excluded in preparing the acid and that what has been left, though too minute in quantity to affect the iodide test (which requires 1 in 20 millions, according to Warington), yet multiplies itself by interaction with the hyponitrous acid by forming nitric oxide, which oxidises in the air dissolved in the solution into nitrous acid again. $(HNO)_2 + 2HNO_2 = 2OH_2 + 4NO \rightarrow 4HNO_2$. This aerial oxidation can be demonstrated upon such a solution of hyponitrous acid as Hantzsch and Kaufmann employed in their experiments, which almost at once blued the iodide test; it being only necessary to leave one portion of it in a deep narrow vessel, such as a test tube half full, and another portion in a shallow basin for ten minutes and then test, when the solution in the basin will be found to liberate more iodine than that in the tube. If in reducing the sodium nitrite, its concentrated solution is shaken, for an hour or two after its main reduction, with excess of the amalgam; if then this solution is either diluted, acidified cau-

tiously with dilute sulphuric acid, and then tested, or precipitated by silver sulphate, away from the light as far as practicable, and the precipitate washed in the dark and converted into the acid for testing, a solution will be obtained which will not blue in the least the iodide reagent for an hour or more, in the dark and provided the constituents of the reagent are pure enough and properly used.*

Against the view, which may be advanced, that hyponitrous acid becomes nitrous acid through oxidation by the air, I must point out that it is difficult to admit that, if the nitrous acid has such origin, it should form so very slowly. A way presented itself to me of deciding the point so far as the exclusion of nitrous acid goes ; it has, however, in my opinion, not served to do so. If, in preparing sodium oximidosulphonate, the sulphur dioxide is used in excess, every trace of nitrite ought, presumably, to get sulphonated ; if then the oximidosulphonate is fully hydrolysed into oxyamidosulphonate, as it presumably can be, then, in the conversion of the latter salt into hyponitrite and sulphite by potassium hydroxide there will be no oximidosulphonate present to simultaneously revert to nitrite and sulphite. Therefore, the silver hyponitrite from such a source should be obtainable absolutely free from nitrite, and should furnish a solution of hyponitrous acid also free from nitrous acid. Such silver hyponitrite I endeavoured to prepare, and then tested the acid got from it. The complication presented itself that such an acid is not quite free from

* My way of applying the test is that followed by Warington (*Chem. News*, 1885, **51**, 39), except that, having potassium iodide of high quality, I used it instead of Trommsdorf's zinc iodide solution. In the dark, a blank test will remain for hours without the least blueing. Acetic acid has no advantage over pure sulphuric or hydrochloric acid.

sulphurous acid, as was shown by its bleaching a minute quantity of iodine solution. That it showed also inactivity for a time upon the iodide and starch reagent was due in part certainly to the presence of the same impurity. The solution did, however, begin to act upon the reagent sooner than this in a blank test began to grow blue. But this was no proof that hyponitrous acid passes spontaneously into nitrous acid. For, first, there is the possibility of nitrous acid having been present through not quite complete sulphonation and hydrolysis in the production of the hyponitrite: this nitrous acid would indeed have been converted into nitric oxide by the sulphurous acid retained by the silver salt, but when all this was gone, the nitric oxide would have become nitrous acid again by oxidation. Secondly, it is almost a certainty that the oxidation by the air of the sulphurous acid will have induced oxidation of some hyponitrous acid, in accordance with the observations of Mohr, M. Traube, van t'Hoff and Jorissen, Engler and Wild, Bach, etc.

Quantitative estimation of hyponitrous acid.—Hyponitrous acid can be estimated accurately both gravimetrically (Zorn) and volumetrically (Thum). Solutions of the free acid or of its alkali salts in water or of its other salts in very dilute and cold nitric acid are mixed with excess of silver nitrate and all free acid just neutralised with sodium carbonate or with ammonia. The washed precipitate is either dried and weighed as such, or weighed as metal, or as chloride.

Volumetrically the acid can be estimated, after it has been got into solution in the free state and unmixed with any other acid, by adding a good excess of solution of potassium permanganate to it, leaving it for a quarter of an hour, then adding sulphuric acid, letting stand for another quarter of an hour,

warming to 30° and adding enough oxalic acid, in known quantity, to decolourise, and finally titrating back with permanganate. The hyponitrous acid is thus oxidised ultimately to nitric acid. The oxalic acid should be a decinormal solution, and the solution of permanganate be volumetrically equivalent to it. During the oxidation, much brown manganese hydroxide forms, but this all disappears along with the excess of permanganate when the oxalic acid is added. Ferrous sulphate is unsuitable for use in place of oxalic acid. The process is an excellent one. Hantzsch and Sauer have failed to get good results with it and condemn it, but that is because they have unwarrantably deviated from Thum's directions by acidifying the permanganate before adding it to the hyponitrite. Kirschner has also had no success with the process, at the same time getting results widely different from those of Hantzsch and Sauer. His failure is also sufficiently explained by his deviations from Thum's directions. Kirschner added nearly insoluble salts, such as the barium, strontium, or silver hyponitrite, to the potassium permanganate, having thus the base of the salt present and locally the hyponitrous acid in excess of the permanganate. He then added the sulphuric acid, apparently immediately, and finally titrated back with ferrous sulphate.

Taking 5cc. normal hydrochloric acid as the standard, largely diluting it, adding ice and a cream of precipitated silver hyponitrite up to exact consumption of all the hydrochloric acid, making up to 100cc., and decanting from the bulk of the silver chloride, I have got a solution which, though somewhat turbid with chloride gave, in successive portions of 20cc., all tested within an hour, quantitative results corresponding well with the presence of .155 gram hyponitrous acid in 100cc.,

that is, the quantity equivalent to the hydrochloric acid taken. Next day, the remainder (in very hot weather) showed the presence of .131 gram acid in 100cc., by the same method of testing.

In alkaline solution Thum has found alkali hyponitrite to be quantitatively converted into nitrite by permanganate; I have not examined the point myself. But that nitrite is then formed, and that nitric acid is formed in Thum's acid permanganate method are points I have easily verified by simple qualitative testing. Kirschner doubts that either is produced.

Barium, strontium, and calcium hyponitrites.

Barium hyponitrite is most simply prepared by adding barium chloride to a concentrated solution of sodium hyponitrite and stirring well. It is crystalline and almost insoluble. It has been prepared by Zorn, Maquenne, and Kirschner. It is an unstable and exceedingly efflorescent salt, but Kirschner has succeeded in determining its water of crystallisation satisfactorily. Its formula is $\text{BaN}_2\text{O}_2 \cdot 4\text{H}_2\text{O}$. A crystalline acid salt exists (Zorn).

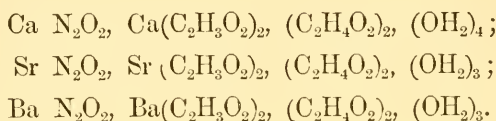
Strontium hyponitrite, $\text{Sr N}_2\text{O}_2 \cdot 5\text{H}_2\text{O}$, Maquenne, Kirschner.

Calcium hyponitrite, $\text{Ca N}_2\text{O}_2 \cdot 4\text{H}_2\text{O}$, Maquenne, Kirschner. Crystalline, very sparingly soluble, and stable, not losing its water even over sulphuric acid. I find that it can be easily precipitated from a fairly concentrated solution of sodium hyponitrite, and can thus be prepared more easily than in the ways followed by Maquenne and by Kirschner, using the silver salt. On account of its stability it is a good hyponitrite to keep in stock. It is sufficiently soluble for its solution to serve

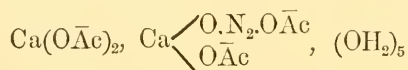
to show the reactions of a hyponitrite with silver, mercuric, mercurous, copper, lead, and other salts.

Calcium, strontium, and barium hyponitroso-acetates.

Some remarkable salts have been described by Maquenne, having the composition expressed by the formulæ—

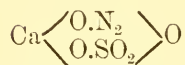


I have prepared and partly analysed the calcium salt, following Maquenne's process, which is to dissolve calcium hyponitrite in 30 per cent. acetic acid until the new salt begins to crystallise out. I kept the acid at about 50° while dissolving in it nearly as much of the calcium salt as it would take up, and then by cooling got the salt. It is remarkable that this can be done without causing more than very slight effervescence. The salt crystallises in short prisms, stable for many days, very soluble in water, in which it gives with silver nitrate the yellow hyponitrite. In spite of its acid composition it is neutral or even slightly alkaline to litmus. To account for its existence and neutral reaction I suggest for it the constitution expressed by the formula—



This represents it as being normal calcium acetate with one fourth of its oxylic oxygen replaced by the hyponitrite radical, or as a double anhydride of calcium acetate and hyponitrite. It thus is made out to have a constitution analogous to that of

a (hypo)nitrososulphate, as determined by Haga and me (*J. Ch. Soc.*, 1895, **67**, 1098)—



Simple hyponitroso-acetic acid, $\text{C}_2\text{H}_3\text{O.O.N}_2\text{OH}$, would be isomeric with acetoneitrosohydroxamic acid, $\text{C}_2\text{H}_3\text{O.N(NO)OH}$, which Hantzsch and Sauer have been trying to prepare. The hyponitrosoacetates are much more stable in water than the (hypo)nitrososulphates, a difference perhaps connected with the fact that sulphuric acid ionises largely, while both acetic acid and hyponitrous acid ionise very little. Heated with water the hyponitrosoacetates decompose like the (hypo)nitrososulphates in cold water.

Mercuric hyponitrite.

Mercuric hyponitrite is a particularly interesting salt, which has not yet been described. Rây has, indeed, described some substances regarded by him as being basic mercuric hyponitrites, but obtained under conditions suggestive of the probability of their being something quite different, and not yet proved by him to be what he has put them forth as being. One of them he obtained by the interaction of solutions of mercuric nitrite and potassium cyanide, a very interesting and remarkable result, should it be confirmed. In any case, his precipitates appear to have nothing at all in common with the normal salt here described, and cannot be obtained in the ordinary way. The existence of this salt was indicated by me in 1871.

Mercuric hyponitrite is obtained by precipitation from a solution of sodium hyponitrite by one of mercuric nitrate. The solution of sodium hyponitrite and hydroxide, obtained by

reducing sodium nitrite (p. 38), largely diluted and, while ice-cold, nearly or quite neutralised with dilute nitric acid (mercurous nitrate serving as indicator, see p. 35), is poured into the mercuric nitrate solution, taken not in excess and containing as little free acid as possible. Very soon, the slightly turbid mother liquor is decanted from the precipitate, neutralised with sodium carbonate, mixed with more mercuric nitrate, so far as necessary, poured back upon the main precipitate, stirred up with it, and soon again decanted. The precipitate should be washed quickly by decantation, since it is liable to be soon all destroyed by its slightly acid mother-liquor.

It is a flocculent, cream-coloured precipitate, easily washed on the filter, and dries up to a light buff-coloured powder, this colour being due, probably, to incipient change into the mercurous salt. Air-dried quickly, on a porous tile, it is hydrated, having the formula $(\text{HgN}_2\text{O}_2)_2(\text{OH}_2)_3$. Dried in the desiccator, it is anhydrous. Being a little sensitive to light, it should be dried in the dark. It dissolves in hydrochloric acid and in sodium-chloride solution, but it is unstable, changing into mercurous salt, and therefore is liable to show turbidity in the chloride solutions. The mercury precipitated as sulphide from a solution of the anhydrous salt in hydrochloric acid, proved to be 76.71 per cent., while calculation for HgN_2O_2 requires 76.92. Its solubility in excess of sodium chloride does not prevent mercuric chloride giving a precipitate with sodium hyponitrite. The solubility of the salt in sodium chloride is a qualitative proof of its normal composition. The alkalinity of the solution is caused by the sodium hyponitrite generated in it. Potassium hydroxide at once decomposes mercuric hyponitrite into oxide, without showing any tendency to produce

basic salts. In very dilute alkali the precipitate is slightly soluble.

What makes this salt so remarkable, not only as a hyponitrite but as a mercuric salt, is the nature of the decomposition which it undergoes. Slowly or quickly, it decomposes into mercurous hyponitrite and nitric oxide,—some of the latter, oxidised by the air, converting some hyponitrite into nitrate. No other mercuric salt decomposes into mercurous salt, while many cupric salts change into cuprous. Ferric oxalate shows just the same kind of change, namely, into ferrous oxalate and carbon dioxide. The most closely related change, however, is that of sodium (hypo)nitrososulphate into sulphite and nitric oxide, the very phenomena being similar, so that, except for the colour-change, I might describe my experience with this salt in the words of the paper by Haga and me on sodium (hypo)nitrososulphate (*J. Ch. Soc.*, 1895, **67**, 1095). Thus, having, on one occasion, left some grams of the salt all night in the desiccator, in form of a pressed cake, just as removed from the filter, then taken it out, and weighed it between watch-glasses, I noticed that it was losing weight on the balance-pan. When the glasses were opened, a strong nitrous odour was observed, the cake soon became grey-white on the surface and, being left loosely covered, grew very hot, and gave out torrents of nitric oxide. It then cooled and underwent no further change, even in the course of months. The whitish colour of the cake was found not to penetrate beyond a millimetre into it, the inside of it being of a uniform yolk-yellow and consisting of mercurous hyponitrite. The surface-coating proved to be mercurous nitrate, largely soluble in water, and had evidently been produced with the assistance of the

oxygen of the air. Not always, however, does the change occur in this striking and rapid way, its progress being gradual and almost imperceptible till complete.

Mercuric hyponitrite is decomposed by heat largely into mercuric oxide and nitrous oxide, but partly into metal and nitric oxide.

Other Hyponitrites.

Mercurous hyponitrite.—This salt has been prepared and analysed by Thum (*Inaug. Diss., Prag*, 1893), who used sodium hyponitrite and mercurous nitrate in obtaining it. The possibility of getting it by the spontaneous decomposition of mercuric hyponitrite has just been described. Rây has also evidently obtained it in a very impure state, not further examined. It can be prepared in the same way as mercuric hyponitrite, using mercurous nitrate in place of mercuric nitrate. It is of a full yellow colour, is blackened by even the weakest solution of alkali, and is soluble in dilute nitric acid, from which it can be precipitated by sodium carbonate. It is a stable salt, but is blackened by bright light. Its decomposition by heat is like that of the mercuric salt, except that much more metal is produced, as is natural. Composition ; $(\text{HgON})_2$.

Cupric hydroxide hyponitrite.—This salt was described by me in 1871 and was also obtained by Kolotow in 1890, but was first fully examined by Thum and has again been examined by Kirschner. Being a basic salt, its precipitation from normal sodium hyponitrite leaves an acid mother liquor, on neutralising which much more of the salt precipitates. It is of a bright pea-green colour and a very stable salt. It may be boiled with water without losing its colour. It is decomposed

by sodium hydroxide and is soluble in dilute acids and ammonia. Thum has shown its composition to be $\text{Cu}(\text{OH})\text{NO}$. It gives water, cupric and cuprous oxides, and nitrous and nitric oxides when heated. By adding copper sulphate in excess to hydroxylamine sulphate and then a very little ammonia, it can also be precipitated in small quantity.

Cuprous hyponitrite cannot be formed. I have tried to get it by precipitating sodium hyponitrite by copper sulphate in presence of free hydroxylamine, but first cuprous oxide precipitated and then by aerial oxidation the basic cupric hyponitrite, which in composition is equivalent to that of cuprous hyponitrite combined with hydroxyl (see above).

Lead hyponitrite.—This salt was also briefly described by me and has been prepared and analysed by Thum. Kirschner has again prepared it and analysed it, but not in a pure state. It precipitates cream yellow and flocculent, but soon becomes very dense and sulphur yellow. Its first state is probably that of a hydrate; Kirschner has mistaken it for a basic salt. The yellow salt is PbX_2O_2 . As Thum has pointed out the yellow precipitate when formed in a weak acid solution, is crystalline and just like ammonium phosphomolybdate. It is soluble in dilute nitric acid and is decomposed by sodium hydroxide but not by sodium carbonate in the cold.

Ammonium hydrogen hyponitrite.—This salt has been described by Hantzsch and Kaufmann who found it to be exceedingly unstable, as was to be expected. That the normal salt could not exist had already been pointed out by me and by Zorn. D. H. Jackson believes, however, that he did obtain it in small quantity in prismatic crystals, but it is exceedingly improbable that he did.

Ethyl hyponitrite.—This alkyl salt was prepared by Zorn and its vapour density taken by him. It is very explosive and not saponified by potassium hydroxide. In the moist state, it slowly decomposes into nitrogen, alcohol, and aldehyde.

Benzyl hyponitrite.—Hantzsch and Kaufmann have prepared benzyl hyponitrite and determined its molecular magnitude cryoscopically. It undergoes similar decomposition to the ethyl salt.

Constitution of the hyponitrites.

Molecular magnitude.—In my first paper nothing could be said as to the molecular magnitude and constitution of the hyponitrites. In 1878, Zorn fully determined their molecular magnitude, finding it to be that containing N_2 , first, by establishing the existence of an acid barium salt and illustrating the similarity of hyponitrites to carbonates (a point which had already been noticed by me), and, then, by preparing ethyl hyponitrite and taking its vapour density at reduced pressure (Hofmann's method). It would therefore be unjust to the memory of this chemist to admit Hantzsch's claim (*Ann.* 1898, **299**, 68) to have finally established this point by determining cryoscopically, in conjunction with Kaufmann, the molecular magnitude of hyponitrous acid in water and of benzyl hyponitrite in acetic acid, valuable as these determinations are. The possibility of determining the molecule of the acid in its solution in water rests upon the fact, also ascertained by these chemists, that the acid only slightly ionises even in very dilute solution. Maquenne, by a somewhat uncertain form of the cryoscopic method, has also shown that in calcium hyponitroso-

acetate the hyponitrite radical cannot be less than N_2O_2 . The strong alkalinity of the alkali salts and the inactivity upon litmus of their partially neutralised solution, first pointed out by me; and the solubility, though only slight, of silver hyponitrite in hyponitrous acid solution (Thum) and in alkali hyponitrite solution are also facts in accordance with the dihydric composition of the acid. Other chemical evidence of the diazo composition of hyponitrites is afforded by the fact of the difficulty if not impossibility, of deoxidising or hydrogenising them (see p. 62). The derivation of hyponitrites from the interaction of hydroxylamine and nitrous acid would only afford evidence of the diazo magnitude of the molecule, if the hyponitrite produced were much larger in quantity than what can be obtained from hydroxylamine by other oxidising agents, or from nitrous acid by other reducing agents.

My colleague, Assistant Professor Ikeda, has kindly made some determinations of the molecular magnitude of sodium hyponitrite by Loewenherz' method (*Z. phys. Ch.*, 1896, **18**, 70), in which the lowering of the freezing point of melted hydrated sodium sulphate by another sodium salt is observed. Loewenherz found that sodium salts behave towards the water of hydrated sodium sulphate almost as non-electrolytes. Prof. Ikeda, in his experiments, employed sodium thiosulphate in place of sulphate, but only because he had been working with that salt and had had large experience with it. Unfortunately, the anhydrous sodium hyponitrite I could furnish at the time was contaminated with 4 or 5 per cent. of carbonate (same mol. wt.), so that the determination of the molecular magnitude can only be regarded as approximate. But it is amply sufficient to decide between $\text{NaON}=53$ and $(\text{NaON})_2=106$, if that were any

longer necessary, after Zorn's decisive researches, supplemented by those of Hantzsch and Kaufmann. Prof. Ikeda has given me the following details:—

M. p. of $\text{Na}_2\text{S}_2\text{O}_3 = 48.4^\circ$ (Tilden found 48.5°);

H. of fusion $= 42.8$ cal. (Ikeda);

Wt. of thiosulphate used $= 40.9$ grams;

Wt. of sodium hyponitrite used $= g$ grams;

Dp. of solidifying pt. $= \Delta T^\circ$;

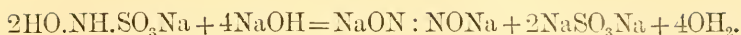
Mol. wt. of hyponitrite $= m$.

$$m = \frac{1}{\Delta T} \cdot \frac{g}{40.9} \cdot \frac{2(273 + 48.4)^2}{42.8} = \frac{g}{\Delta T} \cdot 118.1$$

g	ΔT°	m
.152	0.115	156
.467	0.509	108
1.066	1.260	100
1.238	1.507	97

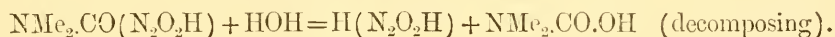
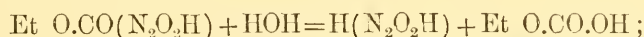
In cases where no decomposition of the salt occurs, the method gives results too high, as, for example, 78.6 instead of 69, for sodium nitrite; but taking into consideration the partial hydrolysis of the hyponitrite that certainly takes place, its molecular weight is clearly indicated as 106 rather than 53.

Constitution.—The constitution $(\text{HNO})_2$ seems to be excluded by considerations of valency, but the positive evidence for $(\text{HON})_2$ is ample. Zorn's observation that ethyl hyponitrite decomposes into nitrogen and alcohol (and aldehyde), even in presence of reducing agents, establishes the diazo constitution of hyponitrites. Never is ammonia or other amine produced in the decomposition of any hyponitrite. Then, the conversion of an oxyamidodisulphonate into hyponitrite affords a beautiful demonstration of the oxylic constitution of the hyponitrites—

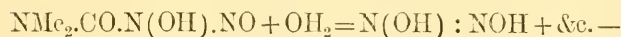
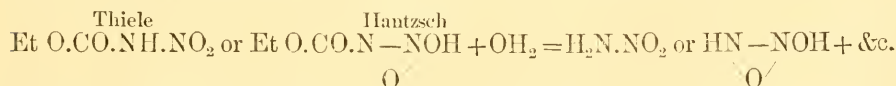


Hantzsch and Sauer have also given an equally convincing proof of the same point, by introducing nitrosyl into dimethylhydroxycarbamide and decomposing the product by alkali (see below). The facts, that cuprous hyponitrite cannot exist and that mercurous hyponitrite, on the other hand, and not the mercuric salt, is stable, point also to the metals being united to the oxygen and not to the nitrogen.

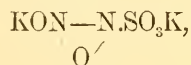
Hantzsch and Sauer, in their desire to prove that nitramine is not $\text{H}_2\text{N.NO}_2$, but a stereoisomer of hyponitrous acid, would have it that their interesting formation of hyponitrous acid from dimethylhydroxy-nitrosocarbamide is analogous to that of nitramine from nitrosourethane—



However, by displaying what $(\text{N}_2\text{O}_2\text{H})$ conceals, namely, the difference between the nitramine and the isonitramine—



it becomes evident that the hydrogen of the water (or metal of the alkali) goes, in the case of the nitramine, to the amidic nitrogen united to the carbonyl, while, in the case of the isonitramine, it goes to the nitroxy or nitroso nitrogen not united to the carbonyl, even if Hantzsch and Sauer's free resort to tautomery could be justified. Surely, this difference is too great to allow of nitramine being treated as a probable or actual stereoisomer of hyponitrous acid. Hantzsch's formula,



for potassium (hypo)nitrososulphate has been shown by Haga and me to have nothing favouring its preference to that of $\text{KON.N.O.SO}_3\text{K}$, which has so much to be said for it.

Analogy of hyponitrites to carbonates and of N_2 to CO.—In hardly forming salts with the feebler metal-radicals, such as aluminium and ferricum ; in decomposing readily into anhydride and water ; and in having its soluble normal salts with very alkaline reaction, hyponitrous acid resembles carbonic acid, as was indicated in my first paper. Zorn, also, in one of his papers, dwells on the analogy of the one acid to the other, pointing out that the salts have the same molecular magnitude, since N_2 and CO are both 28.

As is well-known, the physical properties of nitrogen and carbon monoxide are throughout almost identical. The radicals, carbonyl and di-nitrogen, also, are both bivalent, and occur combined with oxylic, imidic, and alkyl radicals. Thus, $\text{CO}(\text{ONa})_2$ and $\text{COONa}(\text{OH})$ find their analogues in $\text{N}_2(\text{ONa})_2$ and $\text{N}_2\text{ONa}(\text{OH})$. Just as ferric oxalate, $\text{Fe}_2(\text{C}_2\text{O}_2\text{O}_2)_3$ becomes $\text{Fe}_2(\text{C}_2\text{O}_2\text{O}_2)_2 + 2\text{COO}$, so $\text{Hg}_2(\text{N}_2\text{O}_2)_2$ becomes $\text{Hg}_2(\text{N}_2\text{O}_2) + 2\text{NO}$. COO corresponds with N_2O ; also $\text{CO}:\text{NAg}$ to $\text{N}_2:\text{NAg}$. Lastly, ketonic compounds are perhaps represented by azo compounds.

Bibliography

H. Davy, *Researches*, 1800, 254; Hess, *Pogg.*, 1828, **12**, 257; Pelouze, *Ann. Chim.*, 1835, **60**, 151; Schoenbein, *J. pr. Ch.*, 1861, **84**, 202; De Wilde, *Bull. Ac. Belg.*, 1863, [2] **15**, 560, and *Ann.*, 1864, Suppl. **3**, 175; Frémy, *Cr.*, 1870, **70**, 66 and 1208; Maumené, *Cr.*, 1870, **70**, 149; *J. Ch. Soc.*, 1872, **25**, 772; *Ch. News*, 1872, **25**, 153 and 285; *Théorie générale de l'action chimique* (Paris: Dunod), 1880, 286; Divers, *Proc. Roy. Soc.*, 1871, **19**, 425, and, in part, *Ch. News*, **23**, 206; *Ber.*, 1896, **29**, 2324; *Ann.*, 1897, **295**, 366; Divers and Haga, *J. Ch. Soc.*, 1884, **45**, 78; 1885, **47**, 203 and 361; *Proc. Ch. Soc.*, 1887, **3**, 119; *J. Ch. Soc.*, 1889, **55**, 760; 1896, **69**, 1610; Zoin, *Ber.*, 1877, **10**, 1306; 1878, **11**, 1630 and 2217; 1879, **12**, 1509; 1882, **15**, 1007 and 1258; Van der Plaats, *Ber.*, 1877, **10**, 1507; Menke, *J. Ch. Soc.*, 1878, **33**, 401; Berthelot and Ogier, *Cr.*, 1883, **96**, 30 and 84; Berthelot, *Cr.* 1889, **108**, 1286; Dunstan and Dymond, *J. Ch. Soc.*, 1887, **51**, 646; Dunstan, *Pr. Ch. Soc.*, 1887, **3**, 121; Maquenne, *Cr.*, 1889, **108**, 1303; Kolotow, *J. ph. Russ.*, 1890, **23**, 3, abstr. in *C.C.*, 1891, **1**, 1859, and *Bull.*, 1891, [3] **6**, 924; Thum, *Inaug. Diss. Prag*, 1893, and in part, *Monatsh.*, **14**, 294; W. Wislicenus, *Ber.*, 1893, **26**, 771; Paal, *Ber.*, 1893, **26**, 1026; D. H. Jackson, *Proc. Ch. Soc.*, 1893, **9**, 210; Tanatar, *J. Russ. Ch. Soc.*, 1893, [1] **25**, 342; *Ber.* 1893, R., 763; *Ber.* 1894, **27**, 187; *Ber.*, 1896, **29**, 1039; Hantzsch, *Ber.*, 1896, **29**, 1394; Hantzsch and Kaufmann, *Ann.*, 1896, **292**, 317; Hantzsch and Sauer, 1898, **299**, 67; Piloty, *Ber.*, 1896, **29**, 1559; Rây, *Pr. Ch. Soc.*, 1896, **12**, 217; *J. Ch. Soc.*, 1897, **71**, 347, 1097, and 1105; Kirschner, *Z. anorg. Ch.*, 1898, **16**, 424.

On the Geologic Structure of the Malayan Archipelago.

By

B. Kotô, *Ph. D. Rigakuhakushi*,

Professor of Geology, Science College, Imperial University, Tōkyō.

With Plate I.

In the following pages, I propose to give a brief sketch of the geologic and tectonic structure of the island-world of South-eastern Asia usually comprehended under the name of the

taking up the present physical features of Eastern Indies, there by notes have now so service will be done

The great Viennese in a lively picture of Antlitz der Erde,' and per; but as the Ma- ion of his work, and han it was when he

wrote about it, I have found it necessary both to enlarge and to modify his account.

MARINE BIOLOGICAL LABORATORY.

Received

Accession No.

Given by

Place,

**No book or pamphlet is to be removed from the Laboratory without the permission of the Trustees.

On the Geologic Structure of the Malayan Archipelago.

By

B. Kotô, *Ph. D. Rigakuhakushi*,

Professor of Geology, Science College, Imperial University, Tōkyō.

With Plate I.

In the following pages, I propose to give a brief sketch of the geologic and tectonic structure of the island-world of South-eastern Asia, usually comprehended under the name of the Malayan Archipelago. The motive of my taking up the present subject was to enable me to compare the physical features of the island of Taiwan with those of the Far Eastern Indies, there being much in common between them. My notes have now so far accrued as to make me hope that some service will be done by their publication in a connected form. The great Viennese geologist, Prof. E. Suess, has already drawn a lively picture of the structure of these islands, in his 'Das Antlitz der Erde,' and this I have made the foundation of my paper; but as the Malayan Archipelago fills only a small section of his work, and has besides become much better known than it was when he wrote about it, I have found it necessary both to enlarge and to modify his account.

I. Outer Eastern Archipelago.

The Tangla Mountains, in the very heart of the 'Roof of the world', lying between the Himalayan and the Kuen-lun system, run from W. N. W. to E. S. E. From the region of mountain-virgation in the East Tibetan frontier, the Tangla proceed in a south-easterly direction towards the 'peripheric' region, and then, turning to the south, divide up into the parallel chains in Indo-China and Burma, which constitute what is now known as the Further India mountain-system of v. Richthofen.

The westernmost or Arrakan chain, the youngest of the system, is built up of non-fossiliferous sandstones and shales, usually referred to as Cretaceous,¹⁾ accompanied by serpentine, petroleum wells, salt springs and mud-lumps. It, therefore, resembles very closely the Carpathian ranges, the Caucasus, and some parts of the Apennines in many geological features. It has the Flysch facies. Now, this chain (*yoma*) forms the starting point of the *Malayan arc* which goes through the small islands of Cheduba and Reguain, the Preparis and the Cocos to the Andamans and the Nicobars, and then proceeds to Babi (Simalur), the Miocene coal-bearing Nias, and the Mentawai Islands (volcanic according to Maass) as far as Engano. Along this line of elevations, those of *Nicobar Group*, especially Kar Nicobar, have become, geologically speaking, comparatively well known, through the labours of Hochstetter and C. Schwager.²⁾ The geologic components of the Nicobars may be arranged in three

1) Theobald, Geol. Surv. India, 1873. Lately, Noetling has revised the division of the Tertiary system of Burma, and the Axial ridge of the Arrakan-yoma now under consideration, and thinks that they belong to the Cretaceo-Eocene formation. *Vide* Records Geol. Surv. India, Vol. XXVIII, p. 59.

2) 'Reise der Novara', Bd. II, p. 83 *et seq.*

groups, viz., (1) plutonic rocks of the gabbro and serpentine class with hornstone veins, intruding into (2) a complex of micaceous, compact sandstone, shale, marl, and plastic clay, the whole being overlaid by (3) raised coral-reefs. The sandstone banks bear impressions of a Fucoid, *Chondrites nicobarensis*, Hochst. on the plane of sedimentation, like the rock at Biô-kô-sha* on the east coast of Taiwan. The plastic clay abounds in Foraminifers, which belong to the Young Miocene. Geologically important forms among them are *Quinqueloculina*, *Bulimina*, *Lagena*, *Nodosaria*, *Cristellaria*, *Spheroidina*, *Globigerina*, and *Orbulina*.

To the east of the first chain there lies another, which begins near Bahmo in the Yünnan frontier, and extends southwards between the Irrawaddi and Sitoung rivers, the relief becoming lower in the Pegu region, until it becomes merged in the sea between the Andaman group and the Malayan peninsula, which is regarded as its continuation. The upland of Pegu is of Miocene age (the Pegu division); the loose sandstones and clay, of which it is built up, contain many small shark's teeth besides a large *Charcharias* (*Prionodon* sp.), some two inches long, together with *Daphoderma caelata*, Reeve, *Pecten* cf. *favrei* d'Arch. and Haime, and *Cardium* sp. Squaline remains occur particularly in the upper Miocene and in the basal member of the Pliocene (the Irrawaddi division)³⁾ also.

The region lying east of the Sitoung river seems to be mainly Palæozoic, and certainly proved to be in part Carboniferous. Granites, old-looking sandstones and slates, so says Sievers,⁴⁾ extend down to Singapore, and thence to Banka, Billiton,

* The village Biô-kô-sha = 猫公社.

3) Noetling, *loc. cit.* p. 63.

4) 'Asien.'

and finally Borneo, unless, according to the recent researches of Verbeek and Fennema, Karimon Java should be taken to be the true prolongation of the Billiton line.⁵⁾

The Pegu region and the adjoining countries are not free from traces of volcanic activity. In the neighbourhood of Pegan, the basaltic volcano of Puppa-doung, 500 feet high, raises its head from the surrounding Tertiary formation, as well as a trachytic hill near the mouth of the Bassein river. Connection of these with the volcanoes of Sumatra can be traced through Narcondam and Barren Islands.

Sumatra.

Sumatra, the southern continuation of Pegu and the Malayan peninsula, shows, according to Suess,⁶⁾ intrusive granite, schists, Carboniferous* and Tertiary beds with greenstones, all thrown into manifold long ridges producing steep cliffs on the south side, and in the north flattening out into a nearly impenetrable but partly inhabited swampy land. Two parallel chains of volcanoes run along the axis of the mountain folds, one of them near the southern steep coast, whose ejected matter is Miocene andesite, the other lying far in the interior and constituting a chain of modern volcanoes. Many transverse fissures cross the latter chain, along which the seats of active vent are shifting to and fro, as in the Andean cordillera. About nineteen volcanoes can be counted, of which seven belong to the active kind, Gunung Korintji and G. Dempo being lofty summits among them.

5) 'Description Géologique de Java et Madoura.'

6) 'Das Antlitz der Erde.'

* Upper Carboniferous Limestone with *Fusulina*, in Padang on the west coast.

We next come to the Sunda Strait, where the island of Krakatoa made a sudden explosion in 1883.

Java.⁷⁾

Although the large island of Java formed a part of Sumatra at the end of the Miocene period, it differs from its western neighbour in being built up mainly of the Young Tertiary. Palæozoic and still older complexes are only found in the island of Karimon Java, off the northern coast, while Cretaceous and Eocene beds occur in insular patches within the Tertiary upland that constitutes the central axis of the island; the south coast consists mainly of Younger Miocene rocks, while the north is an alluvial plain. Petroleum-wells are located mainly on the line between Samarang and Rembang on the north coast in Miocene beds.

Java owes its special topographic relief not to the sedimentary but to volcanic formations. The enormous masses of extravasation and the vents of volcanic activity are arranged linearly and correspond to the longest extension and the central axis of the island. East Java possesses a double series of longitudinal fissures in its crust crowned with mighty cones, one among them being the active volcano, Semeru, which is the highest elevation in the whole island, being 3,676 mètres above sea-level. The two chains converge at the narrow, middle portion of the island with the extinct Penusspan and Slammat at their junction. Their conjoined, and single fissure extends through occidental Java to the well-known Krakatoa, and thence to Sumatra, traversing by the way three volcanic districts, where

7) Verbeek et Fennema, 'Description Géologique de Java et Madoura,' 1896.

minor fissures or lines of dislocation are oriented parallel and also obliquely to the main line. The Strait of Sunda on the west and that of Bali on the east are also transverse fractures which separate the opposite islands by narrow channels.

There are altogether 131 volcanoes, of which we may mention the following six active ones; Raun, Lemongan, Kelut, Merapi in Solo, Guntur, and Gede, besides Semeru already noticed. The explosion of Papandayang (?Gelungung) in West Java in 1822 is celebrated for having destroyed forty villages and left a large lake in their place.

It is to be remarked in connection with the Javanese volcanoes, that the leucite rocks, so rare in Asia, occur in the island of Bawean, and in G. Ringgit in East Java.

The Small Banda Group.

The volcanic chain, hitherto traced, reaches its end in Pantar, and the zoological boundary established by Wallace⁸⁾ between Bali and Lombok seems to have no geological significance, as is also the case of non-coincidence between the geological and zoological limits in the West Indies. Lombok's neighbour is Sumbawa, in which is located the vent of Tembora, the only match for Papandayang in Java, and well known since its destructive explosion in 1815, which darkened the sky over 3,000 miles. Floris⁹⁾ is volcanic, and its rocks are andesite and basalt. The sedimentaries are tuffs and conglomerate derived from the effusive rocks, and cemented by lime; the conglomerate gradually passes upwards to the coral-reef limestone, the age of which is,

8) Journal Royal Geogr. Soc. 1863, p. 231.

9) Wichmann, 'Bericht über eine Reise nach dem Indischen Archipel.' *Tijdschr. v. h. Kon. Nederl. Aardrijksk. Gen.*, 1891, p. 92.

according to K. Martin,¹⁰⁾ post-Pliocene. A tectonic line, running S. W.—N. E. at the east end of the island, carries three volcanoes, viz., the smoking Parampuwan, Leworoh which exploded in 1881, and Ilimandiri, besides Gunung Api (G. Ija), which is in the solfataric stage.

Andonara is geologically speaking the exact repetition of its western neighbour. Here we have the East Indian Stromboli, called by the name of Pulu Komba. The reef-limestone of the island is now considered by K. Martin¹¹⁾ to be Quaternary, though its age was fixed formerly as that of the Young Miocene,¹²⁾ supported by the occurrence in it of *Clementia papyracea*, Gray, *Celaria singularis* Mart. and *Hydonophora astræoides*, Mart., but as the first of these still survives in the neighbouring seas, its value as the leading fossil of the Miocene must be of doubtful character. It should be remarked by the way that the same fossil bivalve, from an unknown locality in Japan, is said to be in the Museum at Leiden, brought there by v. Siebold. Lately, occurrences of *Clementia* have been reported from several localities in the Neocene of Japan, and one species is still living near the entrance of the Bay of Tokyo. A footnote on page 136 in Wichmann's paper¹³⁾ has given rise to much bitter discussion between Martin and Wichmann in the '*Neues Jahrbuch für Mineralogie*,' etc., 1891-92. The latter¹⁴⁾ taking into consideration the special stratigraphy of these coral limestones and their very elevated position as raised reefs, entertains the view that the coral-limestones, distributed as raised terraces nearly through-

10) *Op. cit.* (9), VII, 1890, p. 265.

11) *Loc. cit.*

12) 'Tertiärschichten auf Java.' p. 36.

13) *Loc. cit.* (9).

14) *Tijdschr. v. h. Kon. Nederl. Aardrijksk. Gen.*, Jaargang, 1892, p. 243.

out the East Indies, belong to the Neogene Tertiary. At many localities, he says, the porous limestone is *covered with* marls of the character of lagoon deposits, and containing Foraminifers such as have been studied by the late C. Schwager¹⁵⁾ in the marls from Kar Nicobar, and in the marls from Luzon by F. Karrer.¹⁶⁾ Both writers class the respective bed as belonging to the Young Tertiary.

It may here be pointed out that A. Agassiz¹⁷⁾ also mentions raised coral-reefs which form terraces of considerable height in the Viti group, as in nearly all other islands of the South Pacific, and he repeatedly speaks of the Neocene age of these limestones but only in order to discriminate them from modern reefs which have not thickness enough to give any support to the Darwin-Dana's depression theory of coral islands.

The discussions about the age of these coral-reef limestones possess special interest for us, because the same formation recurs in great extent in Taiwan and the Rinkiu islands, and the study of these organogenic rocks in Japan has scarcely yet begun.

With Lomblen and Panter we come to the end of the great Malayan arc., and now enter into a difficult but very interesting part of our theme. It is generally asserted that the 'girdle of fire' in the west Pacific starts from the Aleutian Islands and Kamtschatka through Japan and the Philippines to the great arc of the Malay Archipelago, and that a line branches off from the volcano, Dampier,¹⁸⁾ at the western extremity of New Guinea, to the Bismarck Archipelago and the Solomons up to New Zealand,

15) 'Reise der Fregatte Novara', Geologischer Theil, Bd. II, p. 187 et seq.

16) v. Drasche, 'Fragmente zu einer Geologie der Insel Luzon', p. 79.

17) Amer. Jour. Sci., February number, 1898.

18) Naumann, 'Geognosie', I, 1858, p. 92.

forming what is comprehended under the name of the Australian volcanic chain. L. v. Buch years ago pointed out that the long band of Asiatic volcanoes marks off the natural boundary of the Asiatic continent, and this view seems more natural than that of the Bali-Lombok line of Wallace,¹⁹⁾ based on the peculiar distribution of the higher animals. Wallace himself particularly calls attention to the fact that his division of the Archipelago into two regions, characterised by a striking diversity in the natural productions of the islands does not correspond to any of the physical divisions of their surface. The volcanic chain runs through both regions, and geologically they are inseparable.

Looking more into the details of the special position of the Banda volcanoes, which is our immediate subject, we are confronted with difficulties in tracing out the tectonic lines of the region, and the views of geologists are by no means in accord. C. Naumann²⁰⁾ declines to admit the existence of an independent chain here, but sees in the volcanic island of Nila the intersecting point of his middle system, that is, of his Formosa-Nila band with the Sunda chain. Junghuhn,²¹⁾ on the contrary, imagines the Banda series to be a prolongation of Timor, which when he wrote was supposed to be volcanic.

According to Wichmann,²²⁾ the great volcanic band of the Sunda Islands terminates in Panter, since the easterly islands, inclusive of Wetter, carry no volcanic cones, Wetter being for the greater part built up of Palæozoic and Mesozoic beds. With Roma begins a new system, followed by Dammer, Tiow, Nila,

19) Journal Royal Geogr. Soc., 1863, p. 231.

20) *Loc. cit.* (18).

21) 'Java' Bd. II, Leipzig, p. 834.

22) 'Gesteine von der Insel Kisser', *Beiträge zur Geologie von Ostasien*, Bd. II, Leiden, 1887, p. 197.

Serua, Namuk, and the Banda Islands, collectively called the South-west Islands, whose arrangement is curviform, with the inner side towards the north-west. All are entirely volcanic. An active volcano of Riadur crowns Roma; Dammer has the active Wuarlili and a few solfataras; there are volcanoes and solfataras also in Nila; Tiouw has its record of eruption in 1660 and 1693. Upon Serua are three volcanoes, one of which made destructive explosions in 1683, 1694, 1844, and 1862?, while Pulu Manuk (Bird island) has a crater and large deposits of sulphur. In a north-westerly direction we have the Banda Islands, one member of which is Gunung Api (burning mountain) which was in eruption in 1820; and with this apparently ends the Banda chain. We shall come again to it later on.

A glance at the map will suffice to convince us that the geological position of Timor and its neighbouring islands between the Banda and Sunda chains is a peculiar one. Of Sumba or Sandal-wood island there is nothing known from the geological point of view, except that its interior is table-shaped, fringed by raised coral-reefs which are overlaid by marls; but Timor is the classical ground of geology in the whole East Indian Archipelago. Near the boundary between the Dutch and Portuguese possessions, which divides the island into nearly east and west halves, several formations²³⁾ appear to be fairly represented, which, counting upwards, are as follows:—(1) the Archæan amphibolite, (2) the Permian and (3) Trias, and finally reef-limestones. At Baung, not far from the well-known Kupang, the reef-limestones cap the Eocene Nummulitic limestone with *Alveolina*;²⁴⁾ in other places

23) Wichmann, *Tijdschr. v. h. Kon. Nederl. Aardrijksk. Gen.*, Jaargang 1892, p. 255.

24) K. Martin, *ibid.* 1890, p. 269, and Verbeek, *ibid.* 1891, p. 15.

granite, gabbro, serpentine, melaphyre-like rocks, spherulitic quartz-porphry, and Tertiary effusives make their appearance. The Archæan is widespread in the Portuguese domain, accompanied by mica-schist and phyllite; and it seems highly probable that the complex of crystalline schists extends through the islands of Kisser, Letti, and Babbar as far as Buru, thus constituting the second or outer arc of the Banda chain.

At Ajer Mati, south of Kupang, already referred to, a red Crinoidal limestone crops out at many points, which caused the late Beyrich²⁵⁾ and K. Martin²⁶⁾ to write monographs, to the effect that this limestone belongs to the Carboniferous. Lately Rothpletz²⁷⁾ has worked over the collection made by Wichmann, and has come to the conclusion that here we have the Permian or Permo-carboniferous but not the Carboniferous. The collection represents a rich fauna, together with Ammonites (*Arcestes megaphyllus*, *A. tridens*), resembling in many respects those of Salt-Range, Armenia, and Texas. It is to be remarked that none of the exclusively Permian species of Timor occurs in Australia or America. Wichmann made a happy find near Baä in Rotti, lying off the south-west coast of Timor, where a limestone abounds in bivalves upon the plane of sedimentation. These together with other fossils, were also entrusted to Rothpletz for examination, who found many species of *Halobia*, *Monotis*, and *Daonella*. Just as the Permian fauna did not show any close relation to the eastern (Pacific) fauna, so also there are no relations between the East Indian Triassic fauna and that of New Caledonia, New Zealand, and Japan, where the *Monotis*

25) *Abhdlg. d. K. Akademie d. W.*, 1864, Berlin.

26) *Beiträge zur Geologie Ostasiens u. Australiens*, I. p. 15.

27) *The American Naturalist*; 1891, p. 959. Vide also *Paleontographica*, Bd. XXXIX, p. 59.

seems to be represented by the genus *Pseudomontis*. The Liassic and Oolitic fossils of Rotti are represented by *Arietites geometricus*, *Harpoceras* cf. *eseri*, and *Belemnites gerardii*. Sawu is geologically like Rotti. I know nothing about the literature concerning the geology of Ombaai.

The islands Sumba, Timor, Ombaai, and Wetter are remarkably free from volcanoes, though situated amidst the chains of extravasation of subterranean magma. They intervene between the belts of Banda and Sunda, from which we might without hesitation conclude that the two constitute independent series. On this account, Timor is sometimes looked upon geologically as one of the South-west Islands, at other times as a prolongation of the South-east Islands, of the Banda group. After all, Timor and Sumba have not yet got, geologically speaking, their position as true members of the Malayan Archipelago, and they are sometimes even spoken of in connection with Australia.

Be that as it may, the Banda chain of volcanoes, already referred to, is circumscribed exteriorly by the similarly bending series of the South-east Islands which begins either from Kisser or Letti. We will now follow it.

Kisser seems to be a mere cliff of crystalline schists, surrounded by Tertiary and Recent coral-reefs, while Letti consists of rolling hills of Miocene sandstone and marl, with an east-west strike, underlaid by old schists. Moa is a little larger, and geologically somewhat exceptional. A lofty peak like Teneriffa stands on the east coast and is believed to be an extinct volcano, while the low-lying tract consists essentially of coral limestones. As the next island in the series comes Lakor, which is a mere coral limestone. Luang consists of marls and sandstones (Tertiary?), fringed with coral islands; the same should be the case

with Sermatta. Tertiary sandstones with a nucleus probably of crystalline schists make up the island of Babber.* The majority of the Tennimber group belong to the Tertiary and Recent coral formations; and a crystalline limestone and quartzite have been reported to occur in Seera, one of the above group. In the Kei Islands, K. Martin mentions an occurrence of the Eocene limestone with *Alveolina*; Koor resembles it in its geology. Watu-Bella Island seems to be built up of crystalline schists (amphibolites and quartzites), while Tjoor forms an exception, being a volcanic island, an eruption in which in 1559, caused a great damage to the plantations. Ceram-Laut, Suruaki, Goram, and Manawoka consist of crystalline schists, while the minor islands among them are of Recent coral formation. Manawoka may possess an extinct volcano, but this is not quite certain. Ceram (Serang) has, according to K. Martin,²⁸⁾ an equatorial mountain, at least in the western half, is cliffy in the north, and in the south is composed of hills of crystalline schists with Alluvial plains around coves. High mountain limestone (the Buru limestone of Martin), and another complex of limestone, either Quaternary or Tertiary, seem to have a wide distribution, especially in the Buano island. Neovolcanic rocks are scarce, except in the south point of Huamaul or Small Ceram. Wichmann²⁹⁾ cites the occurrence of granite, syenite, quartz-porphry and mica-porphryrite. The northern half of the sister island Buru³⁰⁾ appears to be mountainous, and made up of crystalline schists. Sandstone, overlaid by a Mesozoic (Jurassic) limestone with *Aptychus* and

* An occurrence of the Jurassic limestone is noticed by Suess, in his 'Das Antlitz der Erde', Bd. II, p. 208.

28) *Verhandl. d. Gesell. f. Erdkunde z. Berlin*, Bd. 21, S. 513.

29) 'Beiträge zur Geologie von Ostasiens etc.', Bd. II, S. 201.

30) Martin. *loc. cit.* (28). See also 'Reisen in den Molukken', Leiden, 1894, S. 369, footnote.

Belemnite, slopes gradually southwards. The neighbouring islets of Buano and Kelang are geologically identical with Buru, and non-volcanic. Mampa is entirely unknown.

Amboina and the Uliassers are volcanic, seemingly carrying some volcanic ruins, though none of them is sufficiently known. Nusalaut consists entirely of pyroxene-andesite, save a few patches of raised reefs on its shores. Biotite- and pyroxene-dacites as well as pyroxene-andesite build up the south coast of Saparu and Haruku, likewise the members of the Uliassers, but the raised coral reefs, here called 'karang', of Tertiary or Pleistocene age occupy the greater portion of the insular areas. The same geologic components prevail also in Amboina, except in the peninsula of Leitimor, where the Archaean complex of gneiss and mica-schists makes the foundation, penetrated by biotite-granite and peridotite. This is in turn overlaid by old sedimentaries of grey limestone, shale, and sandstone with interbedded sheets of diabase-porphyrity.

The mass of Wawani on Amboina proper is comparatively well known, through the works of v. Buch, Wallace, and many Dutch writers, as to its supposed geologic nature. Once it was considered to be a dreadful volcano; in later times it has been rejected from the list. K. Martin, in his recent work³¹⁾ which I am here following in its main points, endeavours to re-establish its *active* volcanic nature on the basis of an old document about the catastrophe of February, 1674. A subterranean commotion had been already inaugurated in 1671, and had attained its climax four years later, causing sea-waves, destructive earthquakes, and violent explosions of Monte Wawani. Despite his

31) 'Reisen in den Molukken', Geologischer Theil, 1^{ste} Lieferung, 1898, p. 49.

ingenious interpretation of the account, the phenomena of earthquake and explosion are so hopelessly interwoven, that, from reading his paper, I am almost convinced that all were here dealing no more than a series of violent earthquake shocks. Our experience here in Japan shows that destructive earthquakes and explosions do not fall simultaneously. That Wawani is of volcanic origin and once a seat of activity can, however, be affirmed from the occurrence of pyroxene-dacite which moreover contains cordierite³²⁾ as an accessory. It is very desirable to see the question of Wawani settled, for, upon it largely depends whether the chain of volcanoes of the Moluccas and of the Banda Sea have a claim to separate existence, or are only parts of one system.

From the foregoing, it is evident that the curved chain of islands from Kisser northwards, is only the shattered relic of an old mountain-range, composed mainly of crystalline schists and old massive rocks, beset with the Tertiary limestone and modern coral reefs, with the exception of a part of Moa, the island Tjoor, and possibly also Manawoka, which are said to be volcanic.

Wichmann pointed out the existence of a third, external zone, which may be indicated by a line, going through the Sula group, Great Obi, Misool, and then a part of New Guinea and the Aru group.

It has been repeatedly asserted³³⁾ that there exists a close resemblance between the Banda islands and the Lesser Antilles.

32) Vide Schroeder von der Kolk, *Neues Jahrb. für Mineralogie, etc.* 1896. I. Bd. S. 154. Japanese cordierite occurs in the volcanoes of Asama, Iwaté, and a hill near Nagano (Prov. Nagano), only in the form of *white* ejected blocks with conchoidal fracture, but, so far as I know, has never found in the main body of lava-flows.

33) Suess, 'Das Antlitz der Erde', Bd. I, p. 700. *Ditto*, Bd. I, p. 209.

Following an idea started by L. v. Buch, Prof. E. Suess recently made a critical study of the geology of the Lesser Antilles, which has resulted in the recognition of three zones, viz., (1) the first or inner zone within the concavity of the curved chain, which is exclusively of young volcanic origin; (2) the next which comprehends the mountainous islands; and (3) the third, exterior belt which comprises the Miocene and Quaternary formations.

We meet, according to Wichmann, the analogue of these zones in the Banda Sea with the innermost volcanic arc, constituted by a chain of islands from Roma to Banda, corresponding with that of the Lesser Antilles, caused by the falling in of the crust inside of the above arc. This great sink is itself the Banda Sea, and earthquakes frequent the peripheric zone, as in Amboina, Ceram, and other isles belonging to the series. The second and even the third zone can also be made out, of which enough has been already said in the foregoing pages.

We have a striking representative of geologic homology of the threefold concentric arcs in the Riu-kiu islands,³⁴⁾ which stretch from the north of Taiwan (Formosa) to the south end of Kiu-shu, in which arcs the characteristic three zones can be more easily recognisable than those of the Banda and the Lesser Antilles.

It is to be expressly remarked that in the recent work of Verbeek,³⁵⁾ the volcanic zone of the Banda group is made to go round in enclosed ellipse which passes through the South-west Islands, and then through Gunung Api, off Lucipara and the Tortoise isles, deviating from Wichmann's arc.

34) Kotô, *Chishitsu-gaku-Zasshi* (The Japan Geological Magazine), Vol. IV.

35) Verbeek et Fennema, 'Description Géologique de Java et Madoura', 1896.

II. Inner Eastern Archipelago.

Within and to the immediate north of the great Malayan curve, there are three k-shaped islands, in a line from west to east under the equator, which have been regarded since the time of L. Horner³⁶⁾ as a good example of geographic homologies, though it afterwards turned out that their resemblance is only superficial, for their inner, geologic structure by no means conforms with their outward likeness. These islands, Halmahera (Gilolo), Celebes, and Borneo represent old geologic blocks and other relics of South-eastern Asia, left as giants among the ruins of the long lost land, of which the former sea-board is clearly marked by the Great and Small Sunda groups, and the Banda Islands.

Their geologic relation with the circumscribing Malayan curve is not so clear, as might be looked for, though there exist at several points faint indications of their connection to which I may have occasion to refer in the sequel. But if we turn to the other sides, it soon becomes evident that their affinity with the Philippines is very close, being linked to them either by chains of volcanic islands or series of shattered cordilleras; and these geologic lines converge as we go northwards, presenting the same feature of 'virgation' as in Eastern Thibet.

Borneo.

Posewitz provides us with a concise description of the topography and geology of Borneo, so far as it was known at that

36) Wichmann, 'Die Binnenseen von Celebes', *Petermanns Mittheilungen*, 1893, p. 1. Peschel, 'Neue Probleme'. Wallace, *Jour. Roy. Geogr. Soc.*, London. XXXIII. *Vide also* Wettstein, 'Die Strömung des Festen, Flüssigen and Gasförmigen', p. 49.

time, in his 'Borneo', and I cannot here do better than follow his work, supplementing it with a few notes I have gathered elsewhere.

Borneo is the largest of the Sunda Islands and rather broad. Our knowledge concerning its geography is very imperfect, especially of Beru and the 'central mountain'; the only exception being the coast region and in some degree the interior of the south, and the Chinese district of West Borneo. Mountains are crowded together in the north-west, and trend generally north-eastwards. At about the middle of the chain, one range bends north-west, terminating at Cape Datu, while the south-western branch stretches towards Cape Sambar. Near the junction of the two, the land rises to a considerable height, the so-called 'central mountains', and culminates at the granitic or dioritic G. Tedong. All the principal rivers of Borneo rise in this unexplored region, radiating towards the surrounding seas, each having an independent hydrographic basin of its own, which nearly corresponds to the political divisions, into which this large island is divided. From the central water-shed, the axial ridge proceeds north-eastwards to the peak of Kina-balu, 4175 m. high, the loftiest of the whole island.

Crystalline schists, *alte schieferformation* (probably the Devonian), and the Carboniferous built up the above-mentioned chains, with the strike corresponding to the longest extension of the mountains, and pierced by igneous rocks of granitic and dioritic composition. Among (1), crystalline schists, mica-schist, hornblende-schist and the itacolumite-like quartz-schist are prevalent. By (2), the *alte schieferformation*, we understand that series of rocks, made up of the bluish phyllade and siliceous slate which is conjectured by many to be the Devonian, principally because of the occurrence of some imperfectly preserved

organic remains. The Carboniferous belt flanks the axial ridge on the side of Sarawak and Brunei, and appears again in a few patches on the north. Alternating layers of sandstones and semi-crystalline limestone veined with calcite constitute the main bulk of this belt, which harbours the flora of *Vertebraria*, *Phyllothea*, and the bed in the Seba district (the Kinabatangan river) in British Borneo yields *Fenestella* and *Stenopora*, while that of the upper Kapua, Western Borneo, affords us *Marginifera*, all pointing to the rock-system being Devonian-Carboniferous. (3) Clay-slate and siliceous slate are developed elsewhere and considered to have the Culm facies. These three complexes make up the elevated land, which Posewitz termed collectively the *highland formation*.

Quite recently, the first find was made known in the Sâmbas district in Western Borneo, of the Jurassic system of which the upper series³⁷⁾ is characterised by containing the oval *Protocardia*, and *Exelissa*, and the Lias³⁸⁾ by the occurrence of the genus *Harpoceras* of the group *H. radians*. In the Residency of Sarawak, Newton³⁹⁾ announced the discovery of *Alectryonia amor*, D'Orb., which belongs to the Middle Oolite. This is all what we know about the Jurassic system of whole Borneo,* and this formation seems to be confined to the western region of the island.

37) Vogel, *Sammlungen geol. R.-Mus.* Leiden, Bd. V, S. 128.

38) Krause, *ibid.*, Bd. V, S. 154.

39) The Geological Magazine, 1897, p. 407.

* As I have mentioned in the foregoing page 94, Wichmann and Rothpletz brought to light a few typical fossils of the marine Jurassic, belonging to the Malm and Lias in the island of Rotti. Since then, Martin and Vogel, Krause and Newton considerably enlarged our knowledge of the same system in Borneo. Lately, Sagawa found out a fossil, closely resembling *Alectryonia amor*, in Tosa in the island of Shikoku; and Inouyé gave also notice of the occurrence of *Harpoceras* of the species *radians*, Reineck, in the province of Nagato. It is the well-known fact that Neumayr in his celebrated essay on the geographic distribution of the Jurassic Formation, includes the entire region in his hypothetical Sino-Australian

Though the Cretaceous occurs over a limited space in the Seberuang, a tributary to the Kapuas river in West Borneo, it only became well known through preliminary notes by Geinitz.⁴⁰⁾ Among the entombed remains identified, we find *Vola* cf. *quadricostata*, and *Trigonia* cf. *limbata*, indicative of the presence of the Upper Cretaceous. The typical Cenomanian fossil, *Orbitolina concava*, Lamark, is also found as in the Javanese Cretaceous,⁴¹⁾ and the *Gervillia borneensis*,⁴²⁾ Mart. is said to occur in the Sambas district. Not less interesting is the occurrence⁴³⁾ of *Spherulites* and *Radiolites* in the south-eastern part (Martapura) of the island.

In contrast to the Cretaceous, the Tertiary terrene makes up the greatest part of the area, and the outline of the island is indeed determined by the extent of this formation. The highland formation, already referred to, occurs in narrow ridges and sporadic masses, serving as the back-bone and water-shed of great politico-hydrographic basins. These geologic islands project out between the rolling hills of the Tertiary strata, which elevate themselves as they approach the central, axial highland chain, lending special topographic relief to the aspect of the country. From its position the Tertiary is called collectively the upland formation. Shales, micaceous sandstone and limestone prevail throughout the area, and fall into the Older and Younger Series, of which the former may be divided again into

continent; but these various discoveries unfortunately weaken the strength of his theory, and make me almost believe the "Central Mediterranean" of the Jurassic time to extend directly from the Atlantic to the Pacific Ocean.

40) *Zeitschr. d. d. geol. Gesell.* 1883, S. 204.

41) Martin, *Sammlungen, geol. R.-Mus.*, 1890, Bd. IV, S. 209-231.

42) *Ibid.*, Bd. IV, S. 198.

43) *Ibid.*, Bd. IV, S. 117.

three tolerably well-defined étages, viz., (α) the lowest, sandstone, (β) the middle, marl, and (γ) the uppermost, limestone. This complex seems to be developed to full advantage, and at the same time to be best known,⁴⁴⁾ along the Riamkiwa river in Tanah-Laut, South Borneo. The first étage affords some technically important coal, and is characterised by the *Cyrena borneensis*. The marl étage is rich in fossils and full of *Orbitoides* and *Lithothamnium*. The uppermost bed, the horizon of the limestone contains *Orbitoides*, *Nummulites*, corals, and *echinoids*. Basalts and andesites pierce all the beds, but play only an insignificant rôle in rock-formation.

The Younger Tertiary is also coal-bearing, and has been separately grouped from the Old, not on palæontologic grounds but merely on stratigraphic grounds, and lately, Verbeek⁴⁵⁾ has recast his former scheme, and now étage α is left to rest in the Eocene, β is assigned to the Oligocene (Nari group of India), and γ to the Younger Miocene; the Younger Tertiary will thus be Pliocene beds. Diluvial terraces and Alluvial swamps, holding diamond and gold, fill up the drainage basin of Barito, Kapua, Redjang, Mahakkan, Berau, and Bulongan, thus completing the geology of the island.

As I have said at the outset, the principal direction of the back-bone and also the prevailing strike of the old beds of the island is north-easterly. The same is true of the detached masses, wherever they occur, with variable dips to north-west and south-east. As the greater part still remains *terra incognita*, the time has not yet arrived to attempt to unveil the inner

44) Verbeek und Böttiger, 'Die Eocänformation von Borneo.'

45) *Neues Jahrbuch für Mineralogie*, etc., 1892, I, p. 65.

geologic structure, and I am under the impression, after reading Posewitz's work, that even the axial chain does not fall into the category of the folded mountain-range.

Recently, quite a new aspect of the geologic structure of Borneo has been opened by Molengraaff,⁴⁶⁾ who was one of members of the Dutch Borneo expedition in 1893-'94. One of the many discoveries he made is the existence of a chain of andesitic volcanoes, called by him the Müller Mountains, along the south side of the Kapuas river. Hitherto the rarity of neo-volcanic rocks has been considered to be characteristic of this large island; but as exploration has proceeded our former conception seems likely to turn out to be erroneous. On the north of the Kapuas, on the Sarawak frontier, there exists an east-west striking, folded mountain range, consisting of slate, hornstone, and sandstone (Palæozoic?). This Upper Kapua range seems to keep its direction far into the Mahakkan river district in East Borneo (Kutai), and the same holds true of the volcanic Müller chain and the Schwaner ridge. The latter trending north-eastwards forms the political and hydrographic boundary of the Kapua and Barito basins, and belongs to the category of tilted mountain-ranges with steep southerly cliffs, but sloping gradually to the north in the plateau like upland of the Melawi basin. Such is a brief account of Molengraaff's preliminary notice, differing greatly from former notions as to this district.

After all, we must confess that our data are too scarce to give insight into the geologic structure. The late Neumayr⁴⁷⁾ rightly asserted that Borneo's position in the Eastern Archipelago

46) *Petermanns Mittheilungen*, Bd. 41, 1895, p. 203.

47) 'Erdgeschichte', Bd. II, 1887, p. 657.

bears the same relation to that of Mexico amidst the Andese-Rocky system, it being a matter of great difficulty to decipher its connection with the neighbouring great mountain-systems.

Whether the axis of the Malay peninsula sweeps over to the Seratus ridge of Borneo, or the Banka-Billiton line goes over to Cape Sambar of West Borneo, nothing can be said with certainty, though a mere glance at the map would lead the observer to imagine the latter to be the case, though Verbeek⁴⁸⁾ believes rather in the prolongation of the Banka tectonic line to the islet of Karimon Java. One point seems to be certain, that the highland formation with intrusive granites represents the tin-bearing Billiton and Banka with a laterite cover, exactly like the opposite West Borneo; and the same holds true for the granitic Karimata.

Cape Mangkalihat (Kamiongan) in the Strait of Makassar appears to have some genetic relation with the north arm of Celebes; and the orographic condition near Darvel Bay suggests that a ridge goes through the series of the Sulu Islands to the south-western tongue of Mindanao from the interior of North Borneo, but this remains as a fancy until the geology of the intervening islets becomes known. The massive of Kina-balu in North Borneo should form the continuation of the Zambales-Paragua chain in the Philippines.

New Island.⁴⁹⁾—A small island about 100 yards square, rose from the sea during the earthquake of November, 1897. It lies to the south of Banguay, North Borneo. The ground is clay? traversed by cracks from north-east to south-west, covered with

48) 'Description Géologique de Java et Madoura.'

49) The Geographical Journal, 1898, p. 298.

sandstone and coral fragments. From the fissure inflammable gases are exhaled. Its emergence was accompanied by two sea-waves, a rumbling noise, as well as a furious wind. This shows that the sea-bottom between North Borneo and Paragua is geologically not quite at rest.

Celebes.

Stratigraphically speaking,⁵⁰⁾ granite, greenstones, gneiss, mica-schist and quartzite constitute the foundation of Celebes, overlaid by thick, red clay, and then by grey clay, marl, fine and coarse sandstones, which make alternating beds of marine, lacustrine, and terrestrial origin, harbouring rich fossils. Upon the grey clay rests the thick Neocene limestone of coral formation, which in the interior rises up to an elevation of 1000 mètres, while the same rock on the coast lies in direct contact with the living coral reefs. At some place, there are young lacustrine deposits in the form of a fresh-water quartzite, and bog iron ore, with animal and plant remains.

The main mountain-ridge runs in the meridional direction along the west coast with north-east deflection at the north end, the southern extremity being joined at one point to Lombok by a submarine plateau, and at another point to Floris, probably through the Saleiyer island. From the middle of the island one arm of land projects out to the south-east, and another to the north-east, thus giving a k-shaped outline to the whole Celebes. Both tongues of the land belong to young geologic formations.

The meridional ridge seems mainly to be built up of plutonic and Archaean rocks, which at the north end opposite Cape

50) P. Sarasin, *Verh. d. Gesell. f. Erdkunde. z. Berlin*, XXIII, 1896.

Kamiongan (Mangkalihat) in Borneo, turns at first north-east, and then due east, with the tectonic basin of the Gulf of Tomini in the inner (south) side of the mountain-curve. P. and F. Sarasin⁵¹⁾ crossed between Buol and Marisa in the western tract of the northern arm of Celebes, and found old eruptives and thick, red (Tertiary?) clay in the interior, with modern coral reefs on the shore, but not a trace of neo-volcanic effusives. The same explorers made another overland journey between Amurang and Gorontalo, across the northern peninsula, and made known the existence of a meridional tectonic line through Bolang and Malibaga. The westerly region lying between this line and the before-mentioned Buol-Marisa area is occupied by a granitic nucleus with a mantle of gneiss and shale, the latter being overlaid by Pliocene conglomerate,⁵²⁾ which is made up of gravels of shale and basaltic materials. The coast is everywhere fringed with recent coral reefs. An equatorial trench fault runs along the south coast and the Lake of Limbotto near Gorontalo is the deepest point of this bicataclase depression between the granitic 'horsts.'⁵³⁾

Along the before-mentioned tectonic line⁵⁴⁾ through Bolang and Malibaga, the peninsular area, including Minahassa, Bolang and Mongondo has been depressed, and upon that sunken socle of conglomerate and *Orbitoides*-limestone⁵⁵⁾ are heaped up several volcanic rocks, by which this portion of the island is characterised. The volcanic line traversing the portion in question represents only the prolongation of a great earth-fissure, which

51), 52) *Zeitschr. d. Gesell. f. Erdkunde. z. Berlin*, Bd. 29, 1894.

53) Wichmann, *Petermanns Mitteilungen*, 1893, S. 9.

54) P. u. F. Sarasin, loc. cit. (46).

55) Martin. *Beiträge zur Geologie Ostasiens*, etc., Bd. III, p. 581.

as Centeno long ago pointed out, and is named the Sangi fissure by Wichmann,⁵⁶⁾ may be traced from the volcano Sanguil in the southernmost point of Mindanao through Butulan (Sarangami), G. Awu in Sangi, G. Api in Siao, submarine solfatara near Bauna Wulu,⁵⁷⁾ and Ruwang to the andesitic Klabat, Lokon, and the basaltic Sempu, in Minahassa in North Celebes. The chain with eleven volcanoes turns in a south-easterly direction, and proceeds through Bolang, Mongondo, and then Boliohutu, whence it leaves the land and enters Tomini Bay. The Tongean Islands and perhaps Tandjong Api,⁵⁸⁾ near Poss, in Central Borneo belong to this long belt.

By the way, it may be noted that in the Sangi belt, the greatest among the volcanic islands is Sangi itself. It carries Gunung Awu, 1500 m. high. It made eruptions in 1641, 1711, 1812, 1856, and so lately as 1892. Its activity is of the Asiatic type. In the last eruption it ejected a large quantity of ashes and sent down voluminous mud-streams. It was accompanied by a shake over an extensive area, earthquakes being felt in Makassar at a distance of 1,200 km. from Sangi, and even on the coast of Floris, where they were followed by sea-waves.⁵⁹⁾

As I have said, the meridional ridge of Celebes runs along the whole west coast, the axis of these mountains being built up of crystalline schist, tourmaline-quartzite, and glaucophane-schist⁶⁰⁾ penetrated and overflowed by andesite and basalt. The whole complex is flanked with tuffs which make a fertile plain along the Strait of Makassar. This in turn is overlaid by the

56) *Zeitschr. d. deutsch. geol. Gesell.*, Jahrg. 1893, p. 546.

57) Wichmann, *Natuurkundig Tijdschrift voor Ned. Indië*, Dl. LVII, 1897, p. 220.

58) P. u. F. Sarasin, *Zeitschr. d. Gesell. f. Erdkunde. z. Berlin*, Bd. 30, 1895, S. 350.

59) Wichmann, *Zeitschr. d. deutsch. Geol. Gesell.*, 1893, S. 545.

60) Wichmann, *Neues Jahrbuch f. Mineralogie, etc.*, 1893, Bd. II, S. 176.

Neocene *Orbitoides*-bearing limestone, forming an inland cliff. Wichmann⁶¹⁾ found leucite rocks in the tuffs, which may justify us in saying that these rocks occur largely among the volcanics of this region. The east chain of South Celebes runs parallel to the west coast of the Gulf of Boni, and, with the already-mentioned west range encloses the long central basin of Walanne with inundation lakes of Tempé and Sidenreng.

The geological history of South Celebes, deduced from the foregoing, may, following Wichmann, be summarised in the following few words. The island of crystalline schist on the west coast had become faulted, and through the meridian fissure the neo-volcanic rocks had intruded and overflowed, and then formed detached islands fringed with the Neocene coral reef, which has become now a compact limestone. At the same time, materials of schists and volcanics, in consequence of transgression, had formed the sandstone, holding *Callianassa Dijkii* Mart., on the Boni coast. At the end of the Neocene time, a considerable negative movement had caused detached islands to unite into a peninsula; the encircling coral reefs and the thick sandstone-deposits had also risen from the sea. During the early Pleistocene time, further changes in the configuration of South Celebes took place. The south was the scene of great eruptions and by the accumulation of the matter ejected Lompo-Batang, as well as Bulu Bonte Uhu were built up. Contemporaneous with these subterranean convulsions, the sandstones of the Boni coast were folded and upraised, thereby producing the tectonic valley of Walanne in the interior. This great longitudinally folded basin

61) 'Leucitgesteine von der Insel Celebes', *Natuurkundig Tijdschrift voor Nederlandsch-Indië*, Deel LIII, Aflevering 3, p. 315.

had been once occupied by the sea, on the bottom of which the Pleistocene sediment had deposited, harbouring a rich fauna, scarcely differing from the now living fauna of the neighbouring seas.⁶²⁾

A brief note on Saleiyar may here be conveniently inserted in connection with Celebes. It is a prolongation in a straight line of the east coast of the south-west peninsula of Celebes, but disjoined from it by the Strait of Saleiyar. The island stretches in a meridional direction and is of narrow east-west breadth. The mountainous, eastern half consists entirely of andesites and trachyte, which had welled out from the meridional fissure, formed at the time when the Gulf of Boni was formed by depression; while the west is rather flat, being built up of tuffs, sandstones, and marls with *Pulvinulina*, *Orbulina* and *Globigerina*, overlaid by the Neocene coral limestone. Igneous rocks form the foundation of the whole island.⁶³⁾

Gilolo.

The likeness in general form of Gilolo or Almahera to Celebes is much closer than to the largest of its sister islands, Borneo, owing to the parallelism of its dislocation-lines—one equatorial, the other meridional—with those of Celebes, tectonic lines which seem to govern also the forms of a few of the neighbouring islands. Gilolo, thickly covered with forests, is a geologically neglected island, and there is too little known about it to give sufficient insight into its tectonic structure. Judging,

62) Schepman in Wichmann's paper, 'Die Binnenseen von Celebes', *Petermanns Mittheilungen*, 1893, p. 18.

63) Wichmann, 'Zur Geologie der Insel Saleijar', *Natuurkundig Tijdschrift voor Ned. Indië*, Dl. LIV, p. 1.

however, from the map subjoined to Schneider's paper,⁶⁴⁾ granite and metamorphic schists, together with a complex of limestone, appear to build up Gilolo, Batian, the non-volcanic Great Obi (Ombira), and the Sula islands, all included in the Moluccas or Spice Islands. According to the recent observations of Künkenthal and Retzgers,⁶⁵⁾ Gilolo's geologic elements are crystalline schists, peridotite, andesite, and other neo-volcanics, besides coral-limestones. Batian is in part andesitic, with some traces of hot springs, and a doubtful volcanic cone.

Along the west coast of Gilolo,⁶⁶⁾ a volcanic chain starts from Makian,⁶⁷⁾ and proceeds, quite independent of the Banda volcanoes, through Tidore, Mitara, Ternate, and Hiri, whence it enters the north arm of Gilolo which carries the Gunungs Tala, Duon, Todekku, Onu, Gamma-Kunorra, Tubaru, and then passes into the Tolo group near Galela Bay, here embracing Tarakan, Manuya, Tobelo, and Duko, the last of which made an eruption in 1550, accompanied by earthquakes.⁶⁸⁾ The andesitic Tidore is an extinct-volcanic island, with hot springs near the shore. Makian made eruptions in April, 1760, 1819, 1846, and in December,

64) *Jahrb. d. k. k. geol. Reichsanstalt*, 1876, p. 113 et seq.

65) Works of both authors are cited in K. Martin's 'Reisen in den Molukken', Geologischer Theil, 1ste Lieferung, 1897.

66) Wichmann, 'Die Binnenseen von Celebes', *Petermann's Mittheilungen*, 1893, p. 3.

67) K. Martin in the work cited above, seems to be at variance with Wichmann as to the starting point of the Moluccan volcanic chain. Martin is disposed to think the chain passes southwards through Batian and Manipa Strait to Wawani in Amboina. As the test point of its substantial continuity, which seems to him to withstand any serious objections that might be raised against it, he produces the fact of the synchronous occurrence of subterranean convulsions; for, these events happened almost simultaneously:

20th, May, 1673. Explosion of the Gamma Kunorra in Gilolo.

12th, July, 1673. Earthquake in Amboina.

12th, August, 1673. Explosion of Gamma Lamma in Ternate.

17th, February, 1674. Explosion of Wawani in Amboina.

68) Wichmann, 'Der Ausbruch des Vulkans Tolo in Halmahera', *Zeitschr. d. Deutsch. geol. Gesell.* 1897, p. 159.

1861. The active Gamma Kunorra exploded in 1673, spreading ashes even to the distant Sangir group; and Ternate, which had shown activity in 1840, experienced a violent explosion also in August, 1673. Makian, Ternate, and the Gamma* Kunorra are the trillings of the Moluccan volcanoes. K. Martin⁶⁹⁾ quotes in his recent work, Valentijn's words: 'Man meint auch, dass dieser Berg (in Makian) nebst demjenigen von Ternate und dem Gammacanorre....., nur ein und dasselbe Grundfeuer haben, welches aus drei verschiedenen Oefen ausbricht und ausdampft. Bald glüht der Eine etwas stärker, bald wieder der andre.' The chain of volcanoes of the Molucca fissure, which we have so far traced, seems to touch Kaboroan of the Talaaur group, whence it proceeds to Namusa, in which is situated the extinct volcano Mengampit. The prolongation of this line goes through Cape S. Augustin to the volcano Apo in Mindanao, where the volcanic chain of the Sangir fissure from North Celebes unites with this tectonic line.

The Philippine Islands.

Within the great Malayan arc, we have seen, there are three large, homologous islands, Borneo, Celebes, and Gilolo, besides a number of dependent isles, forming an island-world in South-east Asia, attaining almost continental dimension. If, therefore, the claim of Australia to be the fifth division of the globe is admitted, Wallace,⁷⁰⁾ would ask for this great archipelago that it be called the sixth.

* The Burmese word *yoma* and the Moluccan *gamma* seem to me to be in close phonetic relation with our *yama*, meaning a mountain.

69) 'Reisen in den Molukken', Geologischer Theil, 1^{ste} Lieferung, 1897.

70) Journal of the Royal Geographical Society of London, Vol. XXXIII, p. 219.

From the inner group of the archipelago, that is to say, Borneo, Celebes, and Gilolo, radial ridges of cordilleras and chains of volcanoes converge, like the frame of a fan, towards the Philippines, which therefore, present a variety of orographic features. Geologically they have been reconnoitered by v. Drasche,⁷¹⁾ and some others, while Prof. Suess has ably sketched the geology of the whole Philippines from his wide knowledge of the literature of these obscure Spanish islands. From a study of them we learn that they have parallel ridges separated by tectonic valleys, one of which extends from the Bay of Butuan to that of Davao in Mindanao, while another goes from the Bay of Lingayen to Manila, disconnecting the main chain of Luzon from the westerly Zambales.

The Sierra de Zambales is a meridional ridge, made up of an old stock of gabbro, serpentine, and diabase-like rock, besides a red, hard siliceous slate (? Radiolarian chert), and at some place a limestone of unknown age. On the east side of the sierra, the whole seems to be overlaid by an enormous thickness of trachytic tuffite, from which the feldspar sands are derived. The latter cover the flat and form the ground of Pampanga, north of Manila. Along the west coast near Masingloc, a thinly bedded marly tuffite makes its appearance, and attains a considerable thickness. This was made the subject of study by Karrer, which resulted in the recognition of many species of Foraminifers, identical with those of Kar Nikobar, usually referred to the earlier Miocene.⁷²⁾ The volcanic, southern Zambales trends a little to the south-east, but its main ridge runs close by the

71) 'Fragmente zu einer Geologie der Insel Luzon', 1878, Wien.

72) R. v. Drasche, 'Fragmente.' etc.

west shore, passes through the islands of Lubang, and the basaltic Calamians, and finally reaches Paragua, which seems to be connected with the north end of Borneo. In Paragua, an old limestone is said to occur. The Zambales-Paragua ridge curves quite like the coast of Annam, just as New Caledonia and New Zealand conform to the outcurve of Eastern Australasia.

The ridge of Northern Luzon forks into two arms, viz., the Cordillera del Norte and the Sierra Madres, with the basin of the Rio Grande de Cagayan between them. In the tobacco-producing region, Isabella and Nueva Vizcaya, of that basin, especially in the former, the earlier Miocene tuffite, and compact sandstone seem to have a wide distribution, as is proved by the occurrence of the typical fossils, viz., *Vicarya callosa* Jenk., *Ranella ranionoides*, Mart., *Rostellaria javana*, Mart., just as in Cebú and Java.⁷³⁾

Separated on the east from the Cordillera del Norte by the Rio de Abra, and the Rio Agno, and on the west, from the Sierra de Zambales by the Golfo de Lingayan there runs the meridional Sierra Toyalina through the maritime provinces of Union, Ilocos Sur, and Ilocos Norte. Chlorite-schist and sericite-schist seem to form the foundation of this ridge, as can be seen in a transverse valley near the port of Vigan. This geological island of crystalline schists, which seem to have some resemblance to the oldest rocks of Taiwan (Formosa), is concealed by its covering of the Agno bed, a complex of sandstone, and breccia derived from the detritus of diabase, gabbro and diorite, which have intruded through and overflowed the Archæicum. At a later time, volcanic activity was renewed through eruptions of trachyte,

73) K. Martin, *Sammlungen des geologischen Reichs-Museums in Leiden*, Bd. V, Heft 3, p. 58.

rhyolite, and hornblende-andesite,* whose derivatives—tuffite and marl, and the contemporaneous deposit of coral limestone cover the greater part of the area. As the submersion still continued, coral reefs and the breccia of coral limestone were formed, being associated with the detritus of young volcanic rocks. The corals which afford the substratum of the reef are *Galaxea*, *Favia*, *Meandrina*, *Porites* and ?*Astreopora*, which scarcely differ from the living ones, and have even left behind an atoll at La Trinidad at an elevation of 4,000 feet. Volcanoes seem not quite at rest, for Monte Sto. Tomas, 3,120 Spanish feet high, was said to have made an eruption or explosion in 1635 or 1641.

The inland chain of the west coast, the Cordillera del Norte, seems mainly to be made up of tuffite and coral reefs, with the extinct volcano of Monte Date in Lepanto; its southern prolongation, the Cordillera Central is of hornblende-andesite.

This main western chain meets at the gabbro massive of Caraballo Sur with the Sierra Madres, which runs up the unexplored east coast of North Luzon.

It is a great pity that our knowledge of the geology of North Luzon is so meagre and defective, that we can draw no inference from it about the geology of Taiwan.

From the Caraballo Sur massive which serves for the watershed of all the great rivers of Luzon, the axial mountain ridge

* Oebbecke has made a microscopic analysis of rocks collected by Semper, and he mentions the occurrence of hornblende-andesite of a pumiceous structure in the military districts of Lepanto and Bentok in Northern Luzon, and on the volcanoes of Iriga, Balusan, Labo, Isarog in Camarines, and in the island of Leyte. All the rest of the volcanic districts are mainly made up of the olivine-bearing angite-andesite of a hyaline type. Feldspar-basalt comes from Mindanao besides andesites. *Neues Jahrb. f. Mineralogie*, etc. Beilage-Band I, S. 452 *et seq.*

runs close by the east shore of the Lake of Bay, and trends south-eastwards. The core of the sierra seems to be of crystalline schists, which occupy a considerable area to the north-east of Manila, overlaid in part by the Eocene Nummulitic limestone, first noticed by v. Richthofen⁷⁴⁾ at Binangonan, on the northern shore of the Laguna de Bay. On the south, the mountain resolves itself into at least three parallel chains, as may be conjectured from the outlines of the peninsulas and islands, as well as from the direction of the chief elevations. The westernmost ridge consists of Tabayas, Burias and Ticao; the peninsula of Camarines constitutes the middle; while Caramuan, Batan, and Samar make up the third ridge. The groundwork of the Tabayas peninsula is crystalline schists, overlaid on the north by the tuffite of Majayjay, and on the south by the later Miocene or Pliocene coral limestone.

As regards the geology, the peninsula of Camarines is similar to that of the preceding. Protogene-gneiss and talc-schist are extensively developed in the Malaguit region, with auriferous veins, while the Pliocene limestone makes up the entire west coast. Workable seams of brown coal occur associated with the above limestone. Moreover, Camarines abounds in volcanoes, of which we may mention Tetas, Colasi, Isarog, Iriya which made an eruption in 1628 or 1648, and lastly Albay, all arranged in one series corresponding to the form of the peninsula, and constituting the Albay or Mayon system of volcanoes. Albay is the type of volcanoes of the Philippines; it presents a beautiful cone, and is in a state of constant activity. It has made fourteen eruptions since 1716, and on the 26th, July,

74) *Zeitschr. d. deutsch. geol. Gesell.*, 1862, p. 358.

1897, it was again active, pouring forth streams of lava and ejecting ashes in large quantities. Liboy and two other localities were destroyed with many of their inhabitants. According to Roth, Caramuan seems to consist also of crystalline schists, and lignite beds; and this peninsula, together with the islands of Batan and Saramar, makes the third, easternmost ridge.

The form of Masbate is geniculate. Its peculiar outline has already attracted the attention of v. Drache. One arm conforms itself to the prevalent, south easterly direction, the other wing assumes a south-westerly trend, oriented exactly like Paragua. Thus the mountain-system diverges just as in the Eastern Alps. Its geology is, however, unknown.

In Cebu, diorite and its tuffs make the foundation, covered with the Nummulitic and the post-Pliocene limestone, with the Miocene marl intercalated between the limestone-complex. The whole has been folded into parallel ridges, corresponding to the direction of the west arm of Masbate.

The Miocene lignite bed* recurs here as in Camarines. The same seam appears in the Isla de Negro, and in West Mindanao near the Bay of Sibuguey. It seems probable, as Suess has rightly remarked, that Cebu, Negro, and West Mindanao constitute an independent system, which starts from Masbate and reaches Borneo through the Sulu group. Sulu or Joló, the largest of the group is basaltic, and fringed with coral reefs. The same is the case of Ilo-ilo, lying further north.

Leyte may be considered as the prolongation of the east arm of Masbate. It is geologically unknown, though it is said

* The marl at the coal mine of Alpaco, 298 m. high, contains *Vicarya callosa*, Jenk., which characterises the later Miocene of the East Indian Archipelago. K. Martin, *Sammlungen des geologischen Reichs-Museum in Leiden*, Bd. V, Heft 3, p. 60. The same fossil recurs in Tsuki-yoshi, Mino province, in Central Japan.

that here occurs hornblende-andesite. The eastern sierra of Mindanao lies in the direction of it. The ridge is composed of an old slate, dioritic conglomerate (like the Agno bed), limestone, and serpentine. Separated from the sierra by the Butuan-Davao basin, there runs a western ridge, nearly parallel to the former. It is a gold-producing chain, being built up of quartzite and clayslate. The eastern sierra ends with Cape S. Augustin, opposite to Gilolo, and the western mountain terminates in Cape Tinaca, pointing southwards to Minahassa in North Borneo.

It now remains for me to consider the volcanic chains. As I have already said, the Molucca chain, starting from Makian, goes through Ternate and the north of Gilolo, then through Tulus or Talaut, and Namusa, and finally reaches the solfataric volcano, Apo, in Mindanao, passing by the way a volcano near Cape S. Augustin. The Sangir chain, on the other hand, comes from the north arm of Borneo and passes through Ruang, Siao, Sangir, Butulan (Sarangani), and the volcano Sanguil near Cape Tinaca, and finally unites with the Molucca system at Apo, 9,000 ft. high, the loftiest cone of the Philippines. The united chain reaches the volcano of Caminguin in Butuan Bay, an island formed in 1871, accompanied by a great eruption. It further touches the trachytic island of Biliran, lying to the north of Leyte, and then continues to the Albay chain of Camarines, already referred to. The crater of Cagua, near Cape Eugano in North Luzon, may be looked upon as its prolongation and the same chain goes through the Babuyans, Batans, and the Bashi Islands. It leaves then the Philippines, and enters the island of Kô-tô-sho (Botel-tobago) of the new Japanese domain. The island of Claro of the Babuyan group is said to be a lofty active volcano, which serves the purpose of gigantic natural light-house.

In conclusion, I must not forget to mention the very important volcanic group of Laguna. Lying between the Zambales-Paragua cordillera on the west and the main sierra on the east, that portion of South Luzon, lying to the south of Manila, was submerged during post-Eocene time, and then effusive rocks got piled up at different periods, creating the andesitic Majayjay and the basaltic Taal. On this account, a portion of the sea became barred in, forming the Lake of Bay, and the Bay of Manila on the north. The water of Bombon should be considered as a crater-lake, in the middle of which appears the central cone of Taal, which is constantly emitting steam and vapours. Besides these two volcanoes, there are Magniling and Sosoncambing, each having its own crater. The andesitic Arayat, north of Manila, is an extinct crater, and the cone of Halcon in Mindoro, is the second in height of all the volcanoes of the Philippine Islands.

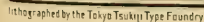


Contents.

	PAGE
Introductory	83
I. Outer Eastern Archipelago... ..	84
The Nicobar Group	84
Sumatra	86
Java	87
The Small Sanda Group	88
Andonara	89
Termination of the volcanic chain of the Sanda Islands ...	90
The Banda chain of volcanoes	91
Timor's geological position	92
The South-east Islands of the Banda Group	94
Amboina, and Mt. Wawani	96
Geologic homology of the Banda Islands, the Lesser Antilles, and the Riū-kiū Islands	97
II. Inner Eastern Archipelago... ..	99
Borneo	99
Tertiary formation of Borneo	102
Geologic structure of Borneo	103
Celebes	106
Volcanic chain of the Sangi... ..	108
Saleiyar	110
Gilolo	110
Volcanic chain of Molucca	111
The Philippine Islands	112
South Luzon	115
Camarines	116
Masbate—Cebu—Leyte—Mindanao	117
The Moluccan chain	118
Volcanic group of Laguna	119

PLATE I.

This Plate is based on the map, Bijlage, I., 'Kaart van den Oost-Indischen Archipel,' subjoined to the recent work of Verbeek et Fennema, *Description géologique de Java et Madoura*. I consulted also Berg-haus's *Physikalischen Atlas, Gewässerkunde*, No. X. Tectonic lines and the zones of volcanoes of the Sangirs, the Moluccas, and the Philippines in the map are my own.



Horizontal Pendulums for the Mechanical Registration of Seismic and Other Earth Movements.

By

F. Omori, D. Sc.

Professor of Seismology, Tokyo Imperial University.

With Plates II—XII.

I.

1. Observational seismology requires not only seismographs to record the comparatively sudden and violent movements of the ground, which constitute earthquakes, but also much more sensitive instruments, to record those imperceptible seismic disturbances and other earth movements, which are always proceeding. The seismometrical work, which has been done in Japan during the last 20 years, has related chiefly to earthquakes of comparatively near origin, the seismographs used being those of Ewing, and Gray and Milne. Each of these instruments registers the more sudden vibrations of the earthquake motion, but is almost incapable of measuring earth undulations of long period, owing to the want of a sufficient approach of the so-called "steady mass" to the neutral equilibrium, and to the existence of a considerable amount of friction between the writing pointer and the record-receiver and elsewhere.

2. It is unnecessary to repeat here the historical sketches of seismographs, horizontal pendulums, etc., which have already

been given by Ewing¹, Davison², Hecker³, Pacher⁴ and others. But with regard to the registration, it must be pointed out that there are two methods of doing this, photographic and mechanical, of which the latter, so far as the observation of earthquakes and similar earth movements is concerned, seems to be the best. Thus, for instance, the Horizontal Pendulum Apparatus of Paschwitz is well adapted for observing the level change of the ground, but, when seismometrically used, it is merely a species of very delicate seismoscope, unless the rate of motion of the photographic paper is very rapid. For, with such a small rate of motion of the paper as was adopted by Paschwitz, about 2 cm. per hour, the photogram shows only the extent of motion of the light point, and tells nothing about the period of vibration of the earthquake motion. In fact it is, I think, a great mistake to take the range of motion in such photograms as the representative, or direct result, of any tilting motion of the ground: firstly, because, in an earthquake, the horizontal pendulum of Paschwitz is usually thrown into its proper oscillations of considerable amplitude, and, secondly because the earthquake movements registered by such pendulums are probably due to the horizontal motion, and not to the tilting of the ground. (See §§ 16,26). With a quick rate of motion of about 30 cm. per hour of a very sensitive photographic paper, we can obtain open earthquake diagrams clearly showing individual movements of the pendulum, as well as the "pulsatory oscillations" or small earth movements

1. J. A. Ewing. Earthquake Measurement. *Memoirs of the Science Department, Tokio Daigaku*, No. 9. 1883.

2. C. Davison. The Horizontal pendulum. *Natural Science Vol. VIII.* 50. April, 1896.

3. O. Hecker. Das Horizontalpendel. *Zeitschrift für Instrumentenkunde*, 1896, Januar.

4. Giulio Pacher. I Microsismografi dell'Istituto di Fisica della R. Università di Padova. *Atti del R. Istituto Veneto di Scienze, etc. Tomo VIII, Serie VII.*—1896-97.

of long period. But the method is expensive, and, besides, the inertia of the mass of the pendulum is too small to be suitable for observing ordinary earthquakes, which throw the pendulum into motion with its own period.

3. With regard to the mechanical method of registration, we can render the instruments as sensitive as we please, by making the "steady mass" sufficiently heavy, say 100 or 200 kilogrammes in weight, as has been done by several Italian observers; or, by greatly lessening the friction between the parts of the machine, as in my Horizontal Pendulum, whose heavy mass is only 3 kilogrammes in weight. (See section III). Further, the definition of the diagram can be made quite sharp, and the rate of motion of the smoked paper, which serves as the record-receiver, can, without expense and trouble, be increased to any extent.

Horizontal Pendulums adapted for mechanical registration have already been successfully tried by Grablovitz¹ and by Cancani². In the horizontal pendulum of Grablovitz the vertical height between the points of suspension and of support is 2 m., while the horizontal distance between the vertical axis and the centre of the heavy mass is only 10 cm., the weight of the latter being 12 kgm. The vertical height in Cancani's apparatus is 5.25 m., and the horizontal distance between the upper point of support and the writing pen 2.7 m., the weight of the heavy mass being 25 kgm. and the complete period of vibration of the pendulum 24 seconds.

1. *Giulio Grablovitz*. Pendoli orizzontali a registrazione meccanica continua. *Boll. d. Soc. Sism. Italiana*, Vol. II.

2. *A. Cancani*. I Pendoli orizzontali, etc. *Boll. d. Soc. Sism. Italiana*, Vol. III.

II.

4. The building, in which my Horizontal Pendulums have been set up, is a brick "Earthquake-proof House,"¹ erected in the grounds of the University (Hongo, Tokyo) by the Imperial Earthquake Investigation Committee, as a sort of a seismological observatory. (See fig. 5.) The structure, which covers an area of 83 sq. m., simply consists of four walls of parabolic section covered with a tiled roof furnished with a skylight, each wall being $5\frac{1}{2}$ m. high, 0.7 m. thick at top and 2.4 m. thick at the ground level. The entrance is the only opening in the walls.

The house, thus forms a kind of a stout hollow column, and its walls, from which the Horizontal Pendulums are suspended, may be considered to be unaffected by the direct impact of winds.

5. My Horizontal Pendulums for recording earthquakes and other earth movements mechanically and continuously, are constructed on the principle of keeping the heavy mass comparatively small and reducing friction to a minimum. As each Pendulum records only the motion normal to its plane, we want, for the complete observation of earth movements, a pair of these machines to be placed at right angles to each other.

The reference letters apply to Pl. II, which illustrates the mechanical details of one of the Horizontal Pendulums, fig. 1 and fig. 2 giving respectively side and front elevations.

The Pendulum consists of a thin brass cylinder, *a*, filled with lead, 16 cm. in height, 10 cm. in diameter and about 14 kgm. in weight, attached a little above its centre of gravity to

1. Designed by Prof. K. Tatsuno, member of the Imperial Earthquake Investigation Committee.

a strut, b , which consists of an iron tube 1.5 cm. in diameter, and of such length that the distance between its end and the axis of the cylinder is 1 m.

The heavy-bob, a , is hung by a fine steel wire, c , from an inside projection of one of the walls of the "Earthquake-proof House," the lower end of the wire being attached to a stirrup, d , pivoted at e , a little above and in front of the centre of gravity of the bob. The tubular strut, b , is furnished at the end with a sharp conical steel point of about 50° , which is pivoted in a conical steel socket, f , of about 120° , fixed to a step-like projection in the lower part of the wall.

The upper end of the wire, c , is attached, by means of a screw, g , to a triangular steel prism, h , whose knife-edge, reduced to two small portions, i and j , works on a steel V-groove, k , properly perforated to allow the passage of the screw g . The V-groove is mounted on a stout arm of hard wood bolted to the upper projection of the wall in such a way that the wire and the knife-edge, whose intersection determines the upper point of suspension of the pendulum, stand at right angles to each other. The pendulum can thus swing freely about its axis, the vertical distance between the points of suspension and of support being $2\frac{1}{2}$ m. The vertical adjustment of the heavy-bob, a , is made by the screw, g , while its horizontal adjustment is made by a screw (not shown in the figures) moving the point of support in the direction normal to the pendulum plane.

As the period of free vibration of the Pendulum is slow, and as the strut, b , is sufficiently long, the axis of the heavy cylinder may be considered as being "steady" not merely with respect to infinitesimal and quick vibrations of the ground, but also with respect to considerable pulsatory or very slow undulations, since

the real earth movements will at least be distinguishable from the proper vibrations of the pendulum.

6. The writing pointer, shown in plan and elevation in fig. 3, consists of a small steel axis, l , 3 mm. in diameter and 5 cm. in height, rigidly attached to a light lever, $m n$, whose shorter forked arm, m , is of brass, and whose longer grooved arm, n , is of aluminium. The axis is pivoted in a vertical position between two small conical sockets fixed in an inverted stirrup, o , which is adjustable along the horizontal metal bridge, p , supported on two stout wooden posts, q , in rigid connection with the ground. (See fig. 4).

Between the two limbs (fig. 4) of the shorter arm, m , of the pointer there is fitted exactly a highly polished small axis, r , 3 mm. in diameter and 3 cm. in height, which forms the prolongation of the central line of the heavy cylinder, a , and which is pivoted in a stirrup, s , fixed to the latter.

To a small U-shaped frame of brass, t , at the end of the aluminium arm of the pointer is hinged an exceedingly light writing index, u , made of a thin triangular piece, about 5 mgm. in weight, cut from a watch spring. The point of the index rests on the record-receiving smoked paper wrapped round a light wooden drum. (See § 7).

The effective lengths of the two arms, m and n , of the writing lever are respectively 28 and 280 mm., the pointer thus multiplying 10 times the horizontal motion of the ground.

It will be observed that the pressure, which the writing index exercises on the record-receiving smoked paper, is a small weight of only $\frac{5}{3}$ mgm., equivalent to one-third of the weight of the index, and this circumstance reduces the friction between the index point and the paper to a minimum. Again, the capability of free

rotation of the axis, r , which serves as the "steady line," very effectually prevents friction coming into play between itself and the limbs of the forked arm, m , of the pointer when the pendulum is recording earth movements. Both of these details are indispensable in making the Horizontal Pendulum sufficiently sensitive to small *pulsatory oscillations*. (See § 13).

7. The record is taken on a smoked smooth paper wrapped round a light wooden drum, v , 942 mm. in circumference and 350 mm. in length, whose axis is formed by a brass rod 8 mm in diameter. The drum, which is turned by clock work¹, w , at the rate of one revolution in an hour, has at the same time a slow motion of translation in the direction of its axis, one of the external prolongations of the latter being screw-cut.

The time-marks on the record-receiver are given by the electric time-ticker, x , connected with a good clock, a signal being made once in a minute.

The drum, which together with its brass axis weighs about $\frac{1}{2}$ kgm. consists of a thin mantle of wood, strengthened by an inner hoop at the middle of its length. Further, to prevent the deformation of the mantle, each end is composed of a frame of the same wood, made up of exactly similar radial pieces, as shown in fig. 1.

8. The above description of the mechanical details applies equally well to each of the EW and NS component Horizontal Pendulums, which differ from each other only in the following two respects.

Firstly, the rate of translation of the drum is, for the EW component apparatus, 4 mm. per revolution, while for the NS component apparatus it is 3 mm. per revolution.

1. Provisionally a pendulum clock has been adopted. It would unquestionably be much better to employ a motor, which drives on continuously, regulated by a governor.

Secondly, the complete periods of vibration of the EW and NS component horizontal pendulums are at present, for a special purpose, set unequal to each other, being respectively 28 and 17 seconds. The period of each pendulum can be raised much above these values, but it was found convenient not to make it much above 30 seconds, in order to prevent the pendulums assuming too great deviations in their daily oscillations and other slow movements.

III.

9. Pl. III illustrates the portable form of my Horizontal Pendulum, recently set up in the Seismological Institute, fig. 6 and fig. 7 giving its front and side elevations.

The heavy-bob of the pendulum is a thin brass cylinder, *a*, filled with lead, $6\frac{1}{2}$ cm. in diameter, 9 cm. in height and about 3 kgm. in weight, attached at a little above its centre of gravity to a strut, *b*, which is an iron rod, 8 mm. in diameter, furnished at the end with a sharp conical point. The strut is pivoted in a conical steel socket, *c*, fixed to the base of a strong cast iron stand, *d*, which is bolted to a foundation column, and from whose top the pendulum is hung by means of a fine wire, *e*. The vertical distance between the points of support and suspension is 1 m., and the horizontal distance between the point of support and the axis of the heavy cylinder 75 cm. The lower end of the wire, *e*, is attached to the cylinder in a manner similar to that in the case of the instrument described in the preceding section.

10. Fig. 8 shows in section and plan the details of the mechanism applied to the top of the cast iron stand, by means of which the necessary adjustments can be effected.

The strut, b , is adjusted to a nearly horizontal position by means of a screw, f , to which the suspension wire is attached, and which passes normally through a closely fitting hole in a steel triangular prism, g . The edge of the knife has all been cut away except two small portions, h and i , on which the prism rests in a V-slot, j , in the inclined hypotenuse face of an isosceles right-angular iron prism, k , soldered to a large square screw, l . The latter passes through two closely fitting stirrups, m , attached to a thick brass plate, n , and the azimuthal position of the heavy cylinder, a , can be adjusted by appropriate movements of the screw, l , by means of the two nuts, o . For properly adjusting the period of vibration of the horizontal pendulum, the whole system is, in its turn, made to move forward and backward on the basal plate, p , by means of a screw, q . Finally, the two screws, r , fixed in the stirrup, s , rising from the basal plate, secures the plate, n , to the latter.

The right-angled prism, k , is so perforated as to allow the free passage through it of the screw, f . Rectangular cuttings, t and u , have also for the same purpose been made in the two plates, n and p .

The basal plate, p , is to be fixed to the top of the cast iron stand, d , with such an angle of inclination that the suspension wire is at right angles to the knife-edge.

11. The complete period of vibration of this form of the horizontal pendulum has been set at 20 seconds, but it can be raised much above this value, if desired, the maximum length of the complete period, with which the pendulum can be kept stable, being about 90 seconds. The comparatively low value of 20 seconds has been chosen for the sake of preventing the deviation of the pendulum becoming inconveniently great, the purpose here

being to observe only seismic and similar slight movements. The writing pointer and the record-receiver are precisely similar to those described in the preceding section, with the difference that the diameter of the wooden drum, which makes one revolution in about 40 minutes, is here $23 \frac{1}{2}$ cm.

IV.

12. I shall now describe some typical diagrams given by my Horizontal Pendulums, the observations having been made, unless otherwise stated, with the instruments set up in the "Earthquake-proof House."

The ground is generally in movement of one kind or other, even when there is no earthquake, but sometimes it is almost still. (See fig. 19.) The duration of the calm epoch varies from a few days to a month or more.

13. The movements of the ground recorded by the Horizontal Pendulums may be divided into two classes, according as they are or are not of seismic origin. A non-seismic disturbance consists of small *pulsatory oscillations*, or movements of slow period¹, which varies usually between 4 and 8 seconds, the maximum range of motion yet observed by me being about 0.2 mm. in each horizontal component.

It is to be noted that in some pronounced storms of pulsatory oscillations, the range of motion is quite as wide as in small earthquakes, although these oscillations are quite imperceptible to the senses, on account of the slowness of period. It is also remarkable that the ground is so often disturbed by such storms,

1. The term *period* is used throughout the paper in the sense of the *complete period*.

each of which generally lasts for some days. Their effects must not be overlooked in determinations of the force of gravity and in other delicate measurements of geo-physics.

The period of the pulsatory oscillations seems to depend, to a slight extent, on the range of motion, the period of the larger movements in a given interval of time being usually a few tenths of a second longer than that of the smaller movements in the same interval. Again, the general average period of the pulsatory oscillations seems to remain nearly constant for a certain length of time, it may be even for several days.

The rate of motion of the smoked paper is, in the present forms of my Horizontal Pendulums, too rapid to allow of pulsations of several minutes period, as observed by Paschwitz, Milne, and others, being discerned.

Pronounced storms of pulsatory oscillations have been generally observed, when strong winds prevailed in Tokyo or its vicinity, as was the case from the 6th to the 7th, September 1898. (See fig. 9). Nevertheless, these movements have been met with in very quiet weathers, as was the case on the 14th and 15th October, 1898. (See fig. 10). For the sake of reference, I give, in Pl. XII, the weather maps for these days.

In the storm of pulsatory oscillations on the 6th and 7th September, 1898, the maximum range of motion was 0.2 mm. in each component. The average period of the oscillations of larger amplitude was 6.0 seconds, while that of the oscillations of smaller amplitude was 5.6 seconds.

In the storm of pulsatory oscillations on the 14th and 15th October, 1898, the maximum range of motion was 0.1 mm. in each component, the general average period being 6.8 seconds.

It must be understood that the period of the pulsatory

oscillations is naturally the same always in both horizontal components.

14. I will next notice three more instances of storms of pulsatory oscillations.

Pulsatory oscillations on the 21st and 22nd May, 1898 ; EW component. The range of motion of one of the greatest movements was 0.16 mm. and its period 5.6 seconds. The motion was not uniform but presented, as is usually the case, alternations of maxima and minima, whose average interval was about 1 minute. The average period of the larger oscillations was 5.5 seconds, while that of the smaller in the same epoch was 5.2 seconds, the general average period being 5.4 seconds.

Pulsatory oscillations on the 5th and 6th June, 1898 ; EW component. The maximum range of motion was 0.15 mm. The average period of the larger oscillations was 5.7 seconds, while that of the smaller was 5.2 seconds, the general average period being 5.4 seconds.

Pulsatory oscillations on the 14th and 15th November, 1898. The average period of vibration was 4.5 seconds, the maximum range of motion being about 0.07 mm. in each horizontal component. The diagram of the NS component is given in fig. 11.

15. The pulsatory oscillations, as to whose reality there can be no doubt, have also been observed by myself with a Paschwitz Horizontal Pendulum newly constructed by Messrs A. Repsold and Sons for the Imperial Earthquake Investigation Committee. Fig. 13 (Pl. VI) exhibits a typical specimen of such movements obtained on the 10th April, 1898, in the University grounds (Hongo, Tokyo), the rate of motion of the photographic paper being 30 cm. per hour, and the proper

periods of oscillation of the EW and NS component horizontal pendulums being respectively 18.8 and 35.5 seconds. It will be observed that, in each component, pulsatory oscillations of period 4.0 seconds are superposed on the proper vibrations of the pendulum, the motion assumed to be horizontal (see § 16) being multiplied 37 times.

Fig. 14 is a similar diagram, with the same multiplication ratio, obtained on the 28th January, 1898, showing one of the most remarkable storms of pulsatory oscillations, which I have so far observed. The average period of vibration of the oscillations was 5.5 seconds, while the maximum range of motion in each horizontal component was 0.15 mm.

16. *On the nature of the pulsatory oscillations.*

The small slow movements, termed here pulsatory oscillations, are not, in general, identical with the microseismic disturbances indicated by ordinary short-period simple pendulum tromometers; or those indicated by a Paschwitz Horizontal Pendulum, when the rate of motion of the photographic paper is small, say a few centimetres per hour. The movements in these cases are simply the proper oscillations of the pendulum, and they have apparently no connection, at least no simple and general connection, with the pulsatory oscillations. Fig. 15 represents an instance, in which the proper motion of the Paschwitz Horizontal Pendulums was great, yet unaccompanied with any pulsatory oscillations.

It is a very important matter to determine whether the pulsatory oscillations are purely horizontal movements or components of tiltings due to undulations of the ground like waves of water. If horizontal movements only, their recorded amplitude would not depend on the proper period of vibration of the horizontal pendulum, but simply upon the ratio of the multi-

plication by the writing pointer. On the other hand, if the pulsatory oscillations be due to tiltings of the ground, the recorded amplitude of motion would depend both on the multiplication ratio of the writing pointer and on the proper period of the pendulum. Thus, if n be the multiplication ratio of the pointer; l , the distance between the end of the strut and the centre of the heavy-bob; φ , the angle of inclination of the axis of support of the pendulum to the vertical; α , the angular amount of the change of level of the ground in direction normal to the plane of the pendulum; and r , the motion of the point of the writing pointer, we have —

$$r = n l \frac{\alpha}{\varphi}$$

or

$$r = n l \alpha \frac{T^2}{T_0^2},$$

in which T is the complete period of vibration of the horizontal pendulum, and T_0 its period when the pendulum swings vertically. In our case, the EW and NS component Horizontal Pendulums are exactly similar to each other, except in the values of the T 's, which are respectively equal to 28 and 17 seconds (§ 8). The ratio of the range of motion as recorded by these two apparatus would, for a given value of α , be as $28^2 : 17^2$, that is to say, as 2.7 : 1. If, therefore, the pulsatory oscillations be due to the tiltings of the ground, the range of motion would, allowing for the alternations of maxima and minima, be shown, on the whole, nearly three times greater in the EW component apparatus than in the NS one. Such, however, is not the case, the range of motion being always equal in the simultaneous diagram of the two component pendulums.

Fig. 12a and fig. 12b are the EW component diagrams of the pulsatory oscillations on the 14th December, 1898, the former

given by the Horizontal Pendulum of the portable form described in section III, and the latter given by the EW component apparatus in the "Earthquake-proof House." It will be observed that the range of motion is the same in the two diagrams, although the two instruments had different periods of proper oscillation and different lengths of struts, and consequently were differently sensitive to tilting movements. (See also § 26).

Again, with respect to the Paschwitz Apparatus diagrams, fig. 13 and fig. 14, the periods of free oscillation of the NS and EW component pendulums were respectively 35.5 and 18.8 seconds, the ratio of the squares of these two numbers being nearly as 4:1; but the range of motion of the pulsatory oscillations was the same on the whole, in the two components.

I conclude, therefore, that the pulsatory oscillations, at least those of the kind here considered, are *horizontal movements* and not tiltings of the ground. The direction of motion of these oscillations is evidently changing from time to time.

V.

17. *Seismic disturbances.* Seismic disturbances, or the movements due to earthquakes, are frequently recorded by Horizontal Pendulums in Tokyo, which is evidently a very favourable place for seismological observation.

They may conveniently be divided into two classes, namely, those of near origin, and those of distant origin. Some typical examples of the former class shall first be given.

18. Every small local shock, as shown in fig. 19, begins with a *preliminary tremor* of a few seconds duration, the motion consisting of vibrations of short period superposed on more or

less distinct slow undulations. The duration of such shocks is short, being, when recorded by ordinary seismographs, usually less than 1 minute. But, when recorded by the Horizontal Pendulums, their duration is found generally to be longer than 10 minutes.

In local shocks, movements of a very long period, say much above 10 seconds, seem not to exist.

19. Fig. 19 gives the NS component diagrams of three small shocks, marked A, B and C, which happened in the night of the 15th and in the morning of the 16th September, 1898.

A. The 16th September, 1898 ; 8.32.31 a.m. The total duration was about 12 minutes, and the duration of the preliminary tremor about 16 seconds. At first quick movements were superposed on slow ones, the average period of vibration in the end portion of the shock being 3.8 seconds. The maximum range of motion was 0.3 mm. in each horizontal component.

B. The 16th September, 1898 ; 4.48.23. a.m. The total duration was about 17 minutes, and the duration of the preliminary tremor about 27 seconds. In the principal portion of the earthquake, there seems to have existed traces of slow undulations, whose period was 5.3 seconds. The average periods of vibration for three successive series of 40 vibrations, measured from about $3\frac{1}{2}$ minutes after the beginning, were found to be 3.5, 3.9 and 5.5 seconds. The maximum range of motion was 0.4 mm. in the EW and 0.5 mm. in the NS component.

C. The 15th September, 1898 ; 4.57.35 p.m. A very small shock, whose total duration was $8\frac{1}{2}$ minutes. The average period of the prevailing waves was 4.3 seconds, these being superposed by others still smaller.

20. The earthquake of the 23rd April, 1898. This was a large earthquake, whose centre was not very distant from the observing station, being under the ocean about 400 km. NE by N of Tokyo. The area of disturbance, within which the shock was strong enough to be felt without instrumental aid, was very extensive, its longest and shortest axes being respectively about 650 and 380 km. Along the east coast of the northern part of the Main Island the shock was sufficiently strong to damage some buildings. In Tokyo itself the earthquake was felt as mild shakings of long duration.

The NS component diagram of the earthquake is shown in fig. 16. (The EW component apparatus was then not ready). The shock began at 8. 37.0 a.m., and, after about 50 seconds of preliminary tremor, the motion became large, till at 1 m. 14 s. from the commencement the pointer got off (at *A*) the record-receiver. At 8 m. 41 s. from the commencement, I put (at *B*) the pointer again on the smoked paper. The motion was then still pretty large, but standing perfectly still, I could feel absolutely nothing of it. The subsequent motion was recorded to the end, the pointer having been purposely displaced from *E* to *E'* and again at *H* in order to avoid the overlapping and confusion of several lines. The total duration of the earthquake was about 2 hours.

The earthquake motion may be considered to have consisted of two kinds of vibrations: firstly, of waves whose periods were short and included between a fraction of a second and about two seconds; and secondly, of waves whose periods were long and varied from 5 seconds to about 12 seconds. Ordinary seismographs would have recorded the waves of the first order, but would have been incapable of recording those of the second.

At first, waves of both kinds occurred together (superposed by some traces of the proper motion of the horizontal pendulum, which, however, are easily distinguishable, on account of the great length of the period of the pendulum itself). The small movements, p, q, qr, st , etc., belong to the first kind, while the large displacements, $a b c, c d e$, etc., belong to the second kind. It will easily be observed that the waves of the first kind soon disappeared, leaving behind only those of the second.

The range of motion of the principal displacements of the waves of the second kind, which I assume to be horizontal movements and not tiltings of the ground, (see § 26 below) were as follows :—

Displacement.	Range of Motion.
$a b$	5.1 mm.
$b c$	5.0 „
$d e$	6.4 „
$f g$	12.6 „

Again, the periods of vibration of the two waves, $a b c$ and $c d e$, were respectively 5.8 and 7.9 seconds. If the period of the motion $f g$ be assumed to be 8 seconds, we find by calculation

maximum velocity = 5 mm. per sec.,

maximum acceleration = 3.5 mm. per sec. per sec.

These values of the maximum velocity and the maximum acceleration are very low, a fact which explains why we do not feel such movements. The range of motion of one of the principal displacements of the first kind, s , was 2.3 mm.

This earthquake enables us on account of its great duration to calculate the average periods in several portions of its motion. Beginning with a point marked B in the diagram, I find for

the average periods of five series of successive 60 complete vibrations —

Successive values of the average period.	Difference.
6.6 seconds.	
7.3 "	0.7 second.
8.1 "	0.8 "
8.9 "	0.8 "
10.7 "	0.8 "

There is thus in this case an apparent arithmetical increase in the average period of vibration, which was in the beginning about 6 seconds and at the end about 11 seconds, the rate of increase of the period amounting to about 0.8 second in every 60 complete vibrations, that is to say, to about 7.5 seconds every hour of the duration of the disturbance. Such an increase in period during an earthquake, which can only be definitely ascertained in shocks of long duration, should be, I believe, hardly perceptible at very great distances from the origin of disturbance.

From the diagram of this earthquake, it is evident that the movements of a great earthquake consist generally of slow undulations superposed upon quick vibrations, different waves being probably generated simultaneously at the centre of disturbance.

One of the after-shocks of this earthquake is also shown in the diagram (fig. 16). The total duration was about 12 minutes, and the average period of the prevailing vibrations in the principal portion was 6.0 seconds, the maximum range of motion being 0.3 mm. Measuring 3 minutes after the commencement, the average period of slow undulations was found to be 7.0 seconds. Near the end the average period was 5.3 seconds..

21. The earthquake of the 26th May, 1898.

This earthquake originated in the province of Echigo, near the town of Tokamachi, about 140 km. NW of Tokyo. In the meizoseismal area, the shock caused much damage to buildings, although it levelled none to the ground. In Tokyo the motion was strong enough to cause people to run out of doors.

The diagram obtained from the two component Horizontal Pendulums are reproduced in fig. 17 and fig. 18. The earthquake began at 3.0.0 a.m., and after 17 seconds the motion became large, till at 90 seconds from the commencement, the EW component pointer went off the record-receiver. The motion in the NS component, which was not so large as in the other component, was successfully recorded to the end. The total duration, notwithstanding the violence of motion, was short, amounting to only about 30 minutes.

The NS component. The motion began with long-period vibrations, of which there were 8 well-defined ones with an average period of 10.4 seconds. The range of motion of one of the most prominent of these vibrations was 5.6 mm., its period being 10.8 seconds. Then followed a great number of well-defined vibrations, whose period, averaged from the first 50 vibrations, was 4.0 seconds. The two maximum movements belonging to this group, which occurred respectively at 62 and 96 seconds from the commencement were the following :—

{ range of motion 11.7 mm., period 4.8 seconds ;
 range of motion 11.7 mm., period 4.2 seconds.

This epoch of the most active motion was followed by a short interval of time, during which the motion was small and superposed by ripples. Then followed again rather well-defined waves of a slightly longer period, interrupted sometimes

by a short interval of irregular movements, the period, averaged from 103 vibrations, being 6.0 seconds. Later on, the period averaged from 68 vibrations was 7.0 seconds.

The EW component. The motion was small and complex during the first 50 seconds, quick vibrations being superposed on slow undulations. The motion became then regular and larger, till at 90 seconds from the commencement the writing pointer went off the smoked paper, when the amplitude became greater than 13.5 mm. and therefore the range of motion greater than 27 mm. The period of this vibration being about 8.5 seconds its maximum velocity and maximum acceleration would be respectively greater than 10 mm. per sec. and 7.4 mm. per sec. per sec.

One of the after-shocks of this earthquake, which took place at 4.54.0. a.m., is shown in figs. 17 and 18. The total duration was about 9 minutes. The motion began with 6 undulations of the average period of 10 seconds, the maximum range of motion being 0.3 mm. in the EW and 0.2 mm. in the NS component. The next 9 undulations were a little quicker, their average period being 6.1 seconds. The average period near the end was 4.6 seconds.

22. As examples of earthquakes, whose origins are at such distances from the observing station that the movements can no longer be registered by ordinary seismographs, I take those shocks which occurred on the 10th and the 12th August, 1898, and on the 7th October, 1898.

23. The earthquake of the 10th August, 1898; 10. 0. 41 p.m.

The meizoseismal area, in which buildings were damaged, landslips produced, etc., was a limited portion of the west of the Province of the Chikuzen (in the Island of Kiushiu), about 900 km. W SW of Tokyo. The total duration was about

9 $\frac{1}{2}$ minutes. The average period of vibration in the preliminary tremor, whose duration was about 22 seconds, was 3.7 seconds. The average period of vibration in the principal portion was 7.2 seconds, the maximum range of motion being 0.15 mm. in each component. Towards the end, the average period was 3.7 seconds.

24. The earthquake of the 12th August, 1898 ; 8.38.33 a.m.

The total duration of this earthquake, whose origin was approximately in the same locality as in the preceding case was about 30 minutes. The average period of vibration in the preliminary tremor, whose duration was 122 seconds, was 3.7 seconds. Then followed 15 larger undulations of the average period of 3.7 seconds, the maximum range of motion being in the EW component 0.2 mm. and in the NS 0.1 mm. The average period of the next 30 vibrations was 7 seconds, the maximum range of motion being in the EW component 0.4 mm. and in the NS 0.2 mm. Towards the end, the average period of 60 vibrations was 7 seconds, and that of the next 60 vibrations 8.1 seconds. The diagrams are given in figs. 20 and 21.

25. The earthquake of the 7th October, 1898 ; 11.1.1 a.m.

This earthquake, which shook, with varying force, the northern part of the Main Island and the southern part of Hokkaido, had its origin in the Pacific, off the eastern coast of the Province of Riknoku, about 640 km. NE by N of Tokyo. The total duration was about 30 minutes, while the duration of the preliminary tremor was 82 seconds. The average period of the prevailing slow undulations in the principal portion was 6.0 seconds, the maximum range of motion being in the EW component 0.3 mm. and in the NS 0.45 mm. The average period later on varied between 3.9 and 6.1 seconds, becoming longer towards the end.

26. The earthquake of the 7th November, 1898 ; 2. 57.11 a.m.

The origin of this earthquake is unknown, but its distance from Tokyo was probably not above 1000 km. The total duration was 20 minutes, while the duration of the preliminary tremor was about 18 seconds. The average period of the prevailing slow undulations, of which there were six, in the principal portion, was 8.2 seconds. From about 2 minutes after the commencement, waves became prominent, whose average period was 4.0 seconds, and whose maximum range of motion was in the EW component 0.7 mm. and in the NS 0.5 mm. Near the end, the average period was 6.6 seconds, the waves being superposed on others with an average period of about 4 seconds.

In fig. 22*b*, is reproduced the EW component diagram of the earthquake as given by the Horizontal Pendulum of the portable form. It will be observed that the diagram, allowing for some insignificant traces of the proper motion of the pendulum, is identical with that in fig. 22*a*, which was given by the EW component Horizontal Pendulum in the "Earthquake-proof House."

The question whether the slow undulations of earthquakes are horizontal movements or due to tiltings of the ground may be discussed from a point of view similar to that stated in § 16 in connection with non-seismic movements. Thus, the groups of undulations marked *a* in the two diagrams are identical with one another. Now the periods of free vibrations of the large and the portable horizontal pendulums were respectively 28 and 20 seconds, while their struts were respectively 1 m. and 75 cm. long, the multiplying ratio of the writing pointer being for each of the instruments equal to 10. If, therefore, the undulations, *a*, be due to the tilting of the ground, the ranges of

motion in the two apparatus would be to each other as 784 : 400, or nearly as 2 : 1. Such, however, is not the case, the range of motion being equal in the two diagrams. Hence I conclude that the undulations in question, as probably also most of the movements of this earthquake recorded by the Horizontal Pendulums, are *horizontal movements*, rather than tiltings, of the ground.

The slow undulations, which occur in the Horizontal Pendulum records of earthquake disturbances emanating from very distant origins, and whose periods are sometimes as long as 20 seconds or even more, are also probably due to horizontal movements of the ground, being evidently of the same nature as the group of undulations marked *a* in the diagrams of figs. 22 *a* and 22 *b*.

VI.

27. *Earthquake disturbances proceeding from distant origins.*

I have already stated in the preceding section that short-period vibrations occur only in the earliest portions of an earthquake, these becoming probably dissipated, by the viscosity of the material constituting the earth's crust, more rapidly than the long-period undulations, which alone remain in the later portion of the shock. Hence it is to be expected that the disturbance coming from a very distant source would consist of only slow undulations.

The duration of a great, distant, seismic disturbance amounts not seldom to $2\frac{1}{2}$ or even 3 hours. The following is an example of such an earthquake.

28. Earthquake of the 17th November, 1898 ; 9. 54.44p.m.

For the diagram see figs. 23 and 24. The total duration

of the earthquake was about $2\frac{1}{2}$ hours. The preliminary tremor, whose duration was about 4 minutes, consisted of vibrations of an average period of 8.4 seconds, with some traces of small movements of a shorter period imposed upon it. Then followed 13 large slow undulations, whose maximum range of motion was in the EW component 1.6 mm., and in the NS 3.0 mm., the average period being 22 seconds. In the next epoch, the period became shorter, the value averaged from 38 vibrations during about 9 minutes being 13 seconds. In the following portion of the shock, the range of motion became small, the value of the period, averaged from successive series of 50 vibrations, being 13, 13, 12, 10, 11, 11 and 10 seconds. Near the end, the average period was 11 seconds.

To estimate the lengths of the waves constituting this earthquake, I shall assume the velocities of propagation of the very first tremors and of the principal undulations to be respectively 13.0 and 3.6 km. per second, these values being the mean results deduced from observations in Europe of the Japan Earthquake (origin in the Pacific) of the 20th February 1897 and of the great Indian Earthquake of the 12th June, 1897. In our case, the period of waves in the preliminary tremor and in the principal portion being respectively 8.4 and 22 seconds, the corresponding wave-lengths come out as about 110 and 80 km.

Fig. 4. Scale about $\frac{1}{4}$

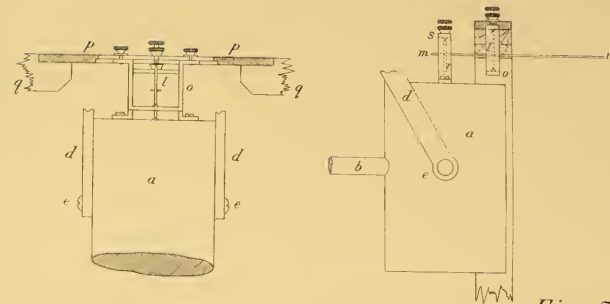


Fig. 5.

Fig. 3. Scale $\frac{1}{2}$



Fig. 2. Scale $\frac{1}{6}$

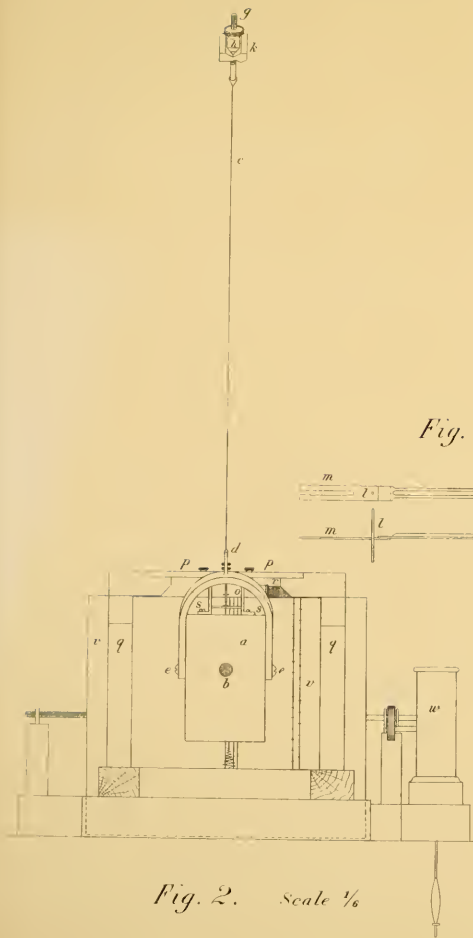
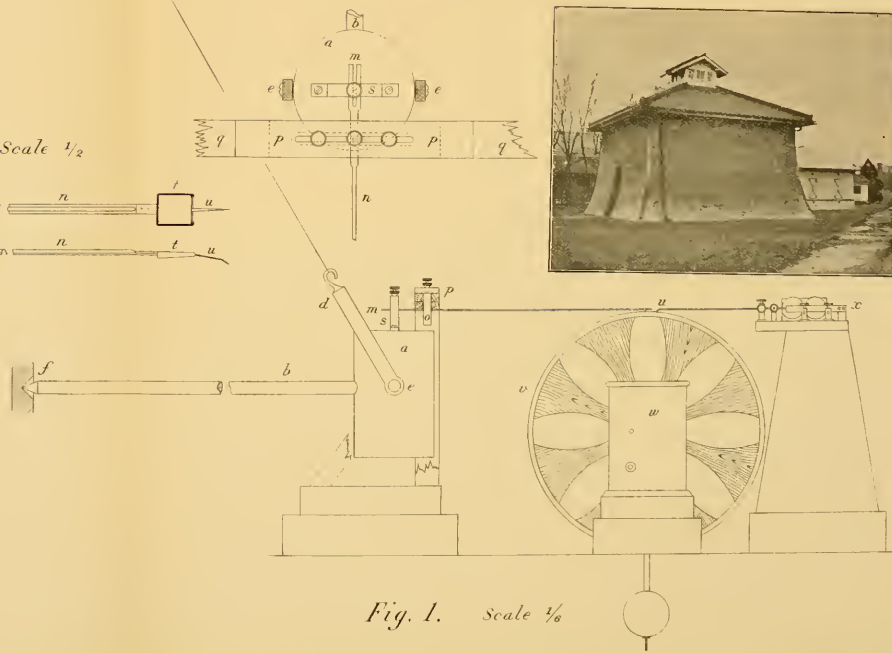


Fig. 1. Scale $\frac{1}{6}$



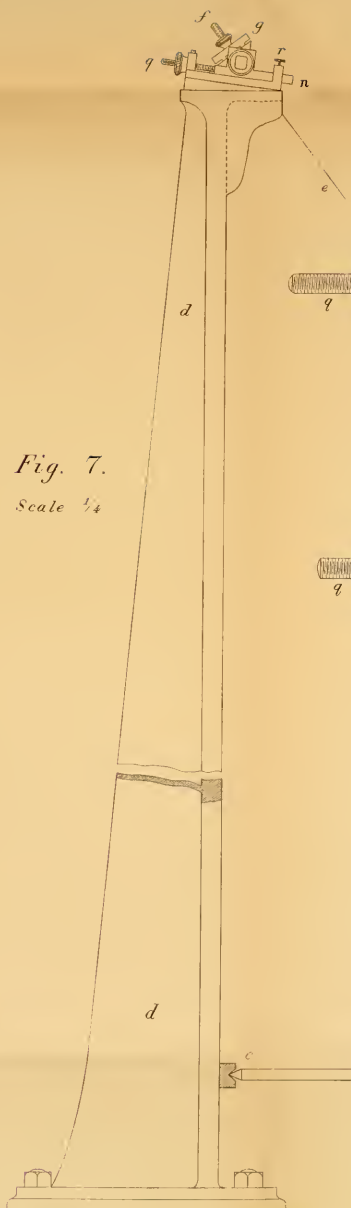
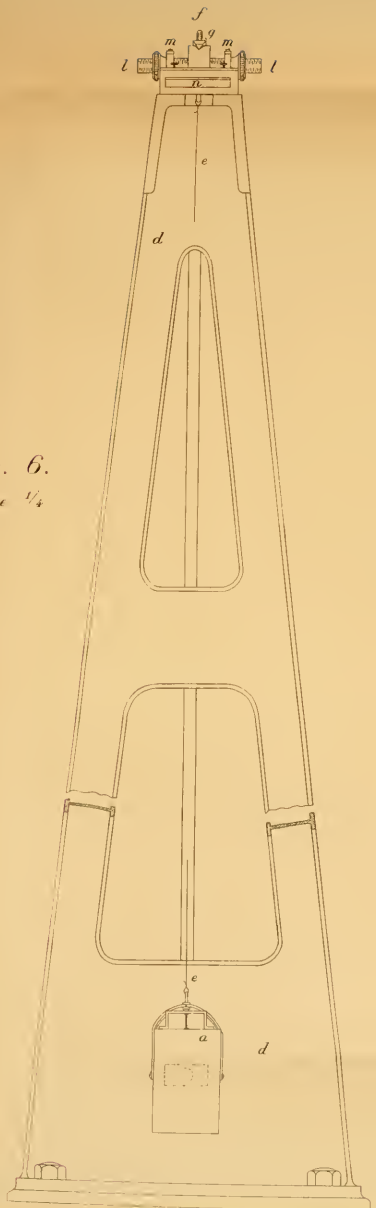


Fig. 8. Scale 1/5

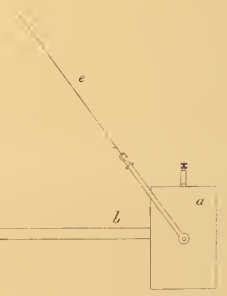
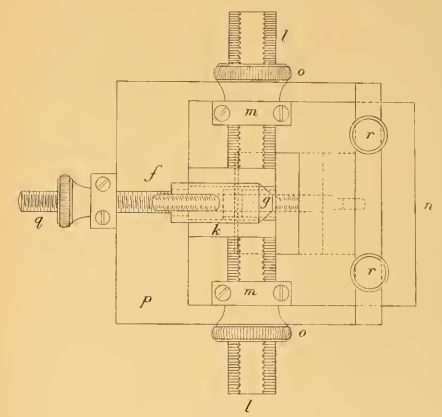
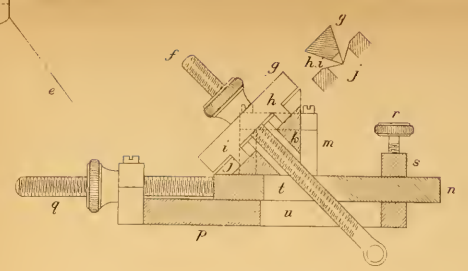




Fig. 9. Pulsatory Oscillations on Sept. 6th—7th, 1898. (NS component).

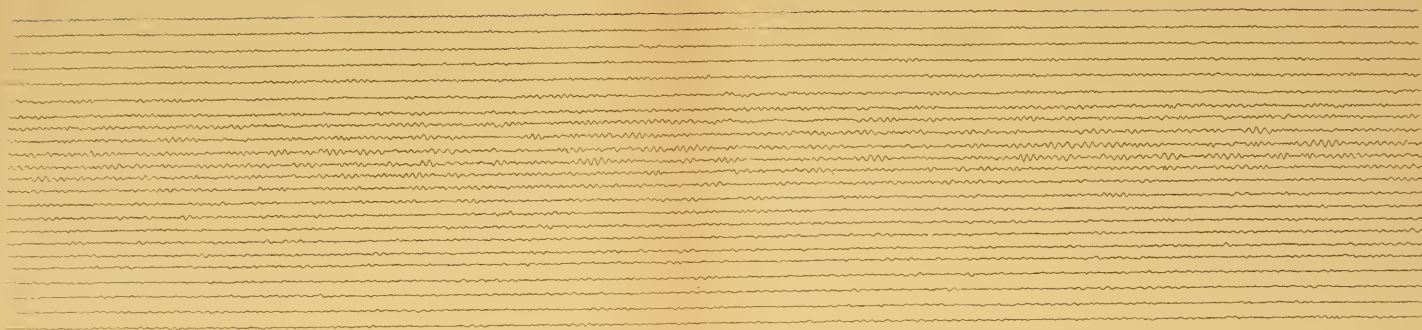


Fig. 10. Pulsatory Oscillations on Oct. 14th—15th, 1898. (NS component).



Fig. 11. Pulsatory Oscillations on Nov. 14th—15th, 1898. (NS component).



Time scale (1 mm=3.7 sec.).

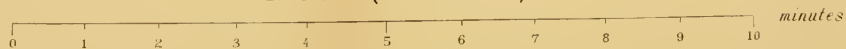
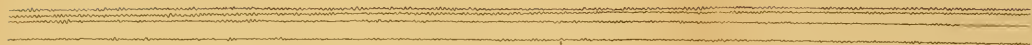
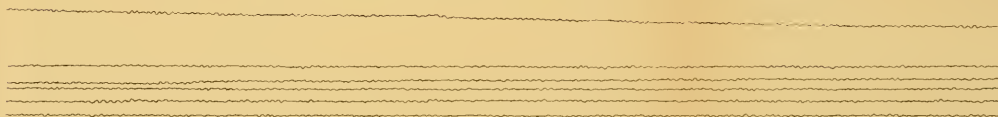


Fig. 12a. Pulsatory Oscillations on Dec. 13th—14th, 1898. (EW component).



Time : 1 tick interval = 1 minute.

Fig. 12b. Pulsatory Oscillations on Dec. 13th—14th, 1898. (EW component).



Time : 1 tick interval = 1 minute.

Fig. 13.

April 10th, 1898.
1. 16. 29 p. m.

April 10th, 1898.
11. 51. 3. a. m.

S

N

E

W

Fig. 14.

Jan., 28th, 1898.
10. 42. 20. a. m.

Jan., 28th, 1898.
1. 16. 20 p. m.

S

N

E

W

Fig. 15.

April 16th, 1898.
1. 11. 18 p. m.

April 16th, 1893.
10. 23. 16 a. m.

S

N

E

W

Time scale

0 5 10 20 30 minutes

Fig. 16. The Earthquake of April 23rd, 1898, and its after-shock. (NS component)

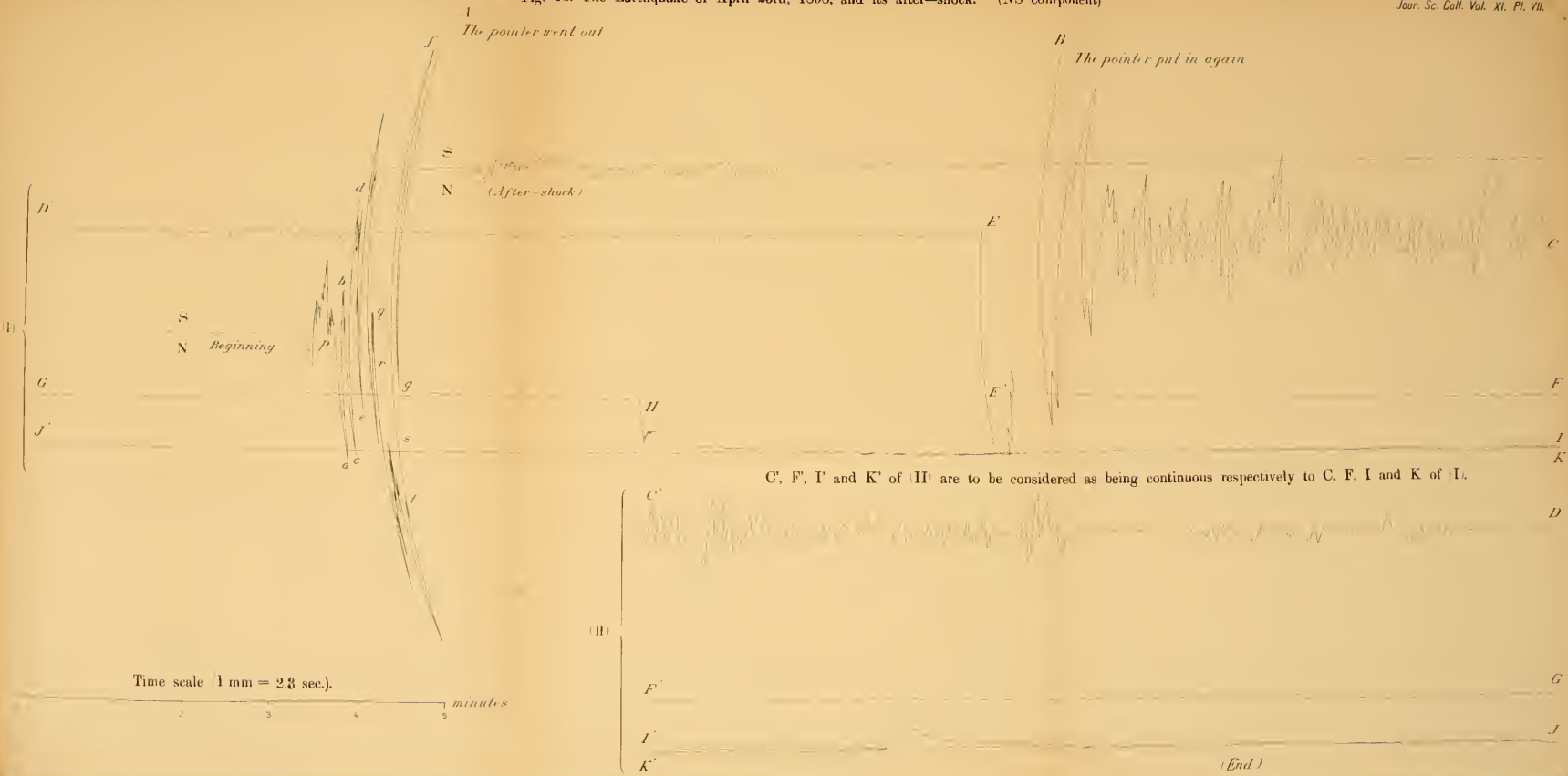


Fig. 17. The Earthquake of May 26th, 1898, and its after-shock. (NS component).

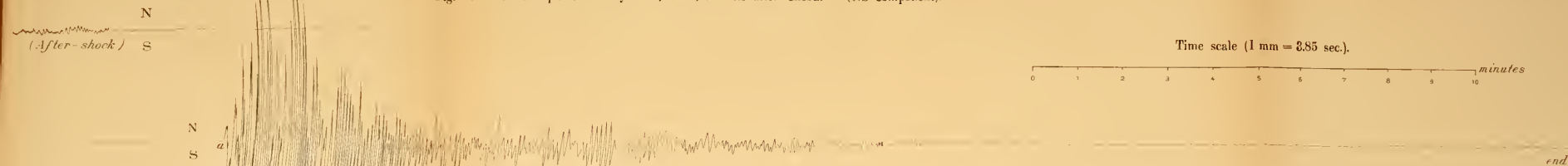
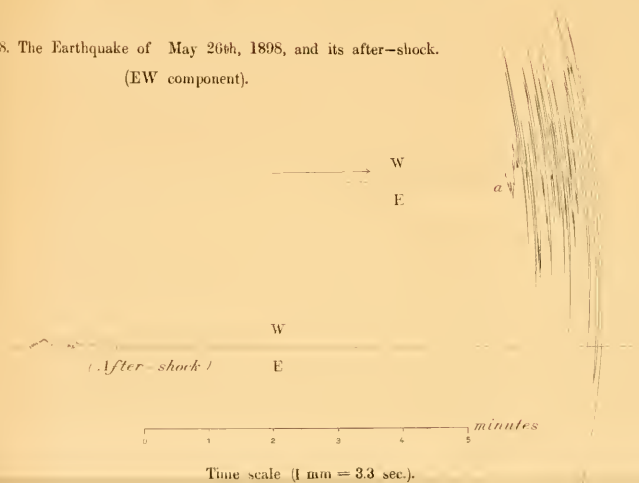


Fig. 18. The Earthquake of May 26th, 1898, and its after-shock.
(EW component).



Pointer went out

b

Fig. 19. Three local shocks (A, B and C) of Sept. 15th-16th, 1898. (NS component).

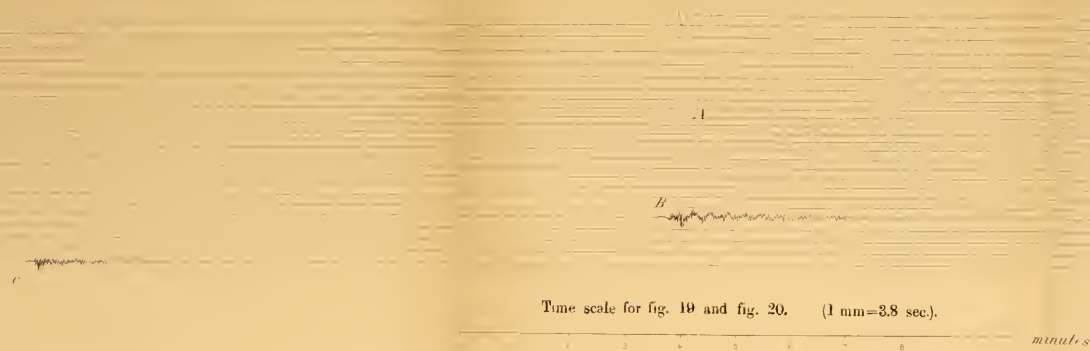


Fig. 20. The Earthquake of August 12th, 1898. (NS component).

Beginning N
N

Fig. 21. The Earthquake of August 12th, 1898. (EW component).

W

Beginning E

Time scale (1 mm = 3.3 sec.).

minutes

Fig. 22a. The Earthquake of November 7th, 1898. (EW component).

W

E

Time scale (1 mm = 3.72 sec.).

minutes

Fig. 22b. The Earthquake of November 7th, 1898. (EW component).

E

W

Time scale (1 mm = 5.03 sec.).

minutes

Fig. 23. The Earthquake of November 17th, 1898. (EW component).



B and b of (I) are to be considered as being continuous respectively to B' and b' of (II). Time : 1 tick interval = 1 minute.

Fig. 24. The Earthquake of November 17th, 1898. (NS component).

A

B

a (9.54.53 p.m.)

S

b

N

B

b

B and *b* of (I) are to be considered as being continuous respectively to B' and *b*' of (II). Time : 1 tick interval = 1 minute.

Oct. 6th 7th, 1898.

Nov. 14th-15th, 1898.

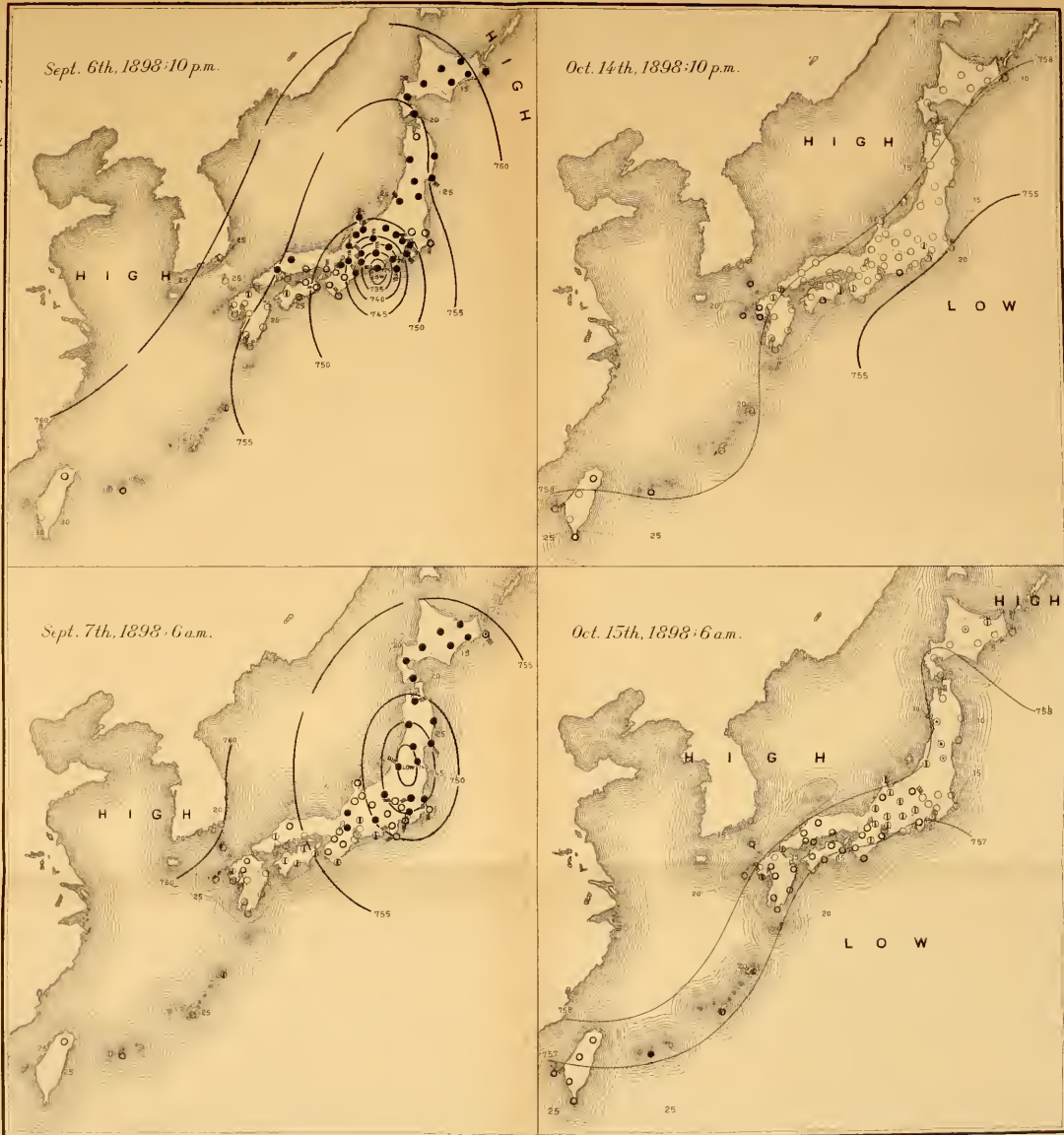
Sept. 6th, 1898: 10 p.m.

Oct. 14th, 1898: 10 p.m.

Sept. 7th, 1898: 6 a.m.

Oct. 15th, 1898: 6 a.m.

- ~ ISOBARIC LINE
 ~ ISOTHERMAL LINE
 CLEAR
 I FAIR
 O CLOUDY
 ● RAIN
 II SNOW
 ○ FOG
 D THUNDER-STORM
 LIGHT WIND
 MODERATE WIND
 STRONG WIND
 GALE
 STRONG GALE
 HURRICANE
 ARROW FLIES WITH THE WIND, ABSENCE OF ARROW INDICATES CALM



Note on the Preliminary Tremor of Earthquake Motion.

By

F. Omori, D. Sc.

Professor of Seismology, Tokyo Imperial University.

With Plates XIII—XVI.

1. It is well known that an earthquake usually begins with movements, whose amplitude of vibrations is much smaller than that of the subsequent motions, which form the principal portion of the shock. These small introductory movements, the "preliminary tremor," whose period is generally very short, are doubtless, in some instances, the cause of the so-called earthquake sound, often heard just before the arrival of the tremblings of the ground. The quickest tremor vibration, which I have ever observed, was one of the after-shocks of the great Mino-Owari earthquake of the 28th October, 1891, instrumentally registered at the temporary seismological observatory set up in the village of Midori in the Néo-Valley, the most central part of the meizoseismal zone, its complete period being only 0.023 second. In the case of some very distant earthquakes, however, the preliminary tremor consists entirely of small slow undulations with a period nearly equal to that in the principal portion.

It has already been pointed out by Professor J. Milne and others that a distant earthquake, as observed by means of delicate horizontal or vertical pendulums, begins with tremors, whose duration increases with the distance of the origin of disturbance from the observing station. What is here discussed is based on the observations of comparatively near earthquakes made in Tokyo and at the Meteorological Observatories of Kago-shima, Fukuoka, Gifu and Miyako, the origins of disturbance being in Japan itself or in the Ocean off its eastern coast.

I may here note that all the earthquake diagrams, from which I have measured the durations of the preliminary tremor, were given, by Ewing's or by Gray and Milne's Seismographs, unless otherwise stated. Each of these instruments, ordinarily at rest, is started on the occasion of an earthquake by means of an electric contact-maker, which is usually made so delicate as to be sensible to a movement of about $\frac{1}{20}$ mm. However, different seismographs at one station, owing to different sensibilities of the contact-makers of the instruments, do not always give one and the same duration for the preliminary tremor of an earthquake, the discrepancy amounting usually to a few seconds. In these cases the longest value of the duration must be regarded as nearest to the truth and is that which has been adopted.

Again, I have excluded all the diagrams of small earthquakes, whose origins were very far off from the observing station, because in these cases, the beginnings of the motion, being slow and extremely small, are very apt to fail to affect the electric contact-maker, and, also because there often exists no well-marked transition from the preliminary tremor to the principal portion of such earthquakes.

By examining the seismographic diagrams of different earthquakes, it will be seen that in general the duration of the preliminary tremor is longer for distant earthquakes than for those of near origins. Its duration in some typical earthquakes, as recorded in the diagrams, I shall now proceed to consider.

2. Observations at the Meteorological Observatory of Gifu (lat. $35^{\circ}27'$, long. $136^{\circ}46'$). The observations at Gifu of the great Mino-Owari earthquake of the 28th October, 1891, and of five of its strongest after-shocks are given in the following table:—

Earthquakes observed at Gifu.

No.	Intensity.	Date.	Time of occurrence.	Duration of the preliminary tremor.
1	Destructive.	28th Oct. 1891	h. m. s. a. m. 6. 37. 11 a. m.	2. seconds.
2	Rather strong.	28th Nov. 1891	9. 39. 19 a. m.	1.3 „
3	„ „	3rd Jan. 1892	4. 21. 13 p. m.	3. „
4	Violent.	7th Sept. 1892	5. 41. 07 a. m.	1. „
5	Rather strong.	10th Jan. 1894	6. 03. 42 p. m.	1.5 „
6	Violent.	„ „ „	6. 45. 28 p. m.	3. „
Mean.....				2.0 seconds.

Of these 6 earthquakes, No. 1 was caused by the formation of a long fault, most remarkably shown in the Néo-Valley, whose central part is about 30 kilometres distant from Gifu. The remaining five earthquakes all originated in the Mino-Owari plain, not far from the same city.

3. Observations at the Meteorological Observatory of Kagoshima (lat. $31^{\circ}35'$, long. $130^{\circ}33'$).

The observations at Kagoshima of the violent earthquake of the 7th September, 1893, and two of its after-shocks were as follows:—

Earthquakes observed at Kagoshima.

No.	Intensity.	Date.	Time of occurrence.	Duration of the preliminary tremor.
1	Very strong.	7th Sept. 1893	h. m. s. a. m. 2. 46. 00	2.5 seconds.
2	Strong.	8th „ „	7. 10. 20 a. m.	1.2 „
3	Weak.	12th „ „	11. 39. 34 p. m.	0.5 „
Mean.....				1.4 seconds.

The origins of these earthquakes were in the southern part of the Satsuma Peninsula, at about 25 kilometers south of the city of Kagoshima.

4. Observations at the Meteorological Observatory of Fukuoka (lat. $33^{\circ}35'$, long. $130^{\circ}23'$).

The observations at Fukuoka of the severe earthquake of the 12th August, 1898, and one of its after-shocks were as follows :—

Earthquakes observed at Fukuoka.

No.	Intensity.	Date.	Time of occurrence.	Duration of the preliminary tremor.
1	Very strong.	12th Aug. 1898	h. m. s. a. m. 9. 35. 34	0.3 seconds.
2	Strong.	„ „ „	1. 03. 15 p. m.	0. „
Mean.....				0.2 second.

The origins of these earthquakes were in the western part of the province of Chikuzen at about 20 kilometres west of Fukuoka.

The duration of the preliminary tremor of No. 1, as recorded by my Horizontal Pendulum in Tokyo, was 122 seconds.

5. Observations in Tokyo. In the following table are given the observations of those earthquakes of comparatively near origin, which were strongly felt in Tokyo.

Earthquakes of near origin observed in Tokyo.

No.	Intensity.	Date.	Time of occurrence.	Approximate position of the epicentre.	Duration of the preliminary tremor.
1	Strong.	15th Oct. 1884	^{h. m. s.} 4. 21. 54 a.m.	In the ocean, probably 100 kil. S.W.	4. seconds.
2	"	15th Jan. 1887	6. 51. 59 p.m.	50 kil. S.W.	3. "
3	"	5th Sept. 1887	3. 23. 23 p.m.	In the ocean, E.	15. "
4	Rather Strong.	5th April 1888	2. 30. 29 p.m.	In the Province of Shimotsuke, 100 kil. N.	10. "
5	Strong.	29th April 1888	10. 00. 33 a.m.	Same as No. 4.	14. "
6	"	18th Feb. 1889	6. 09. 32 a.m.	In the Bay of Tokyo.	10.5 "
7	"	24th Dec. 1891	5. 33. 14 a.m.	70 kil. W.S.W.	7.7 "
8	"	31st June 1892	7. 09. 57 a.m.	In the vicinity, E.	7.6 "
9	Violent.	20th June 1894	2. 04. 10 p.m.	In the vicinity, E.N.E.	6.8 "
10	Strong.	7th Oct. 1894	8. 30. 03 p.m.	In the ocean, E. N. E.	16. "
11	Rather Strong.	30th Nov. 1894	8. 30. 57 p.m.	70 kil. S.W.S. (Focal depth taken into account.)	9.3 "

Mean.....10.0 seconds.

6. Observations in Tokyo, (*cont.*) I will next give the observations in Tokyo of great earthquakes of distant origin.

Earthquakes of distant origin observed in Tokyo.

No.	Intensity.	Date.	Time of occurrence.	Position of the epicentre.	Duration of the preliminary tremor.
1	Strong.	28th Oct. 1891	^{h. m. s.} 6. 39. 11 a.m.	(The great Mino-Owari Eqke.) 288 kil. W.	37. seconds.
2	Weak.	22nd March 1894	7. 27. 49 p.m.	(The great Hokkaido Eqke.) 900 kil. N.E.	109. "
3	Slight.	31st Aug. 1896	5. 09. 33 p.m.	(The great Rikuchugo Eqke.) 430 kil. N.	56. "

4	Strong.	17th Jan. 1897	0. 49. 28 a. m.	(The severe Nagano Eqke.) 170 kil. N.W.	17. seconds.
5*	Weak.	5th Aug. 1897	9. 12. 23 a. m.	In the ocean, about 400 kil. N.E.	45. „
6	Strong.	26th May 1898	2. 59. 57 a. m.	(The severe Echigo Eqke.) 170 kil. N.W.N.	17. „
7*	Weak.	23rd April 1826	8. 37. 00 a. m.	In the ocean, about 400 kil. N.E.	54. „

The positions of the suboceanic origins of the two earthquakes, No. 5 and No. 6, (marked with asterisks), have been inferred simply from the forms of their isoseismal lines on land and are, therefore, to be regarded as being only approximate. These two earthquakes have been excluded in deducing equation (1) below. With respect to the remaining five earthquakes, all of which, except No. 2, originated inland, the positions of their origins have carefully been determined from special investigations and are consequently to be regarded as being exact.

I add here the observation at the Meteorological Observatory of Osaka¹ of the great Mino-Owari earthquake of the 28th October, 1891 :

{(Distance of Osaka from the origin=140 kilometres.)
{ Duration of the preliminary tremor=14 seconds.

7. Comparing the results in §§ 2, 3, and 4 with that in § 6, we see that the duration of the preliminary tremor of an earthquake depends on the distance between the origin and the observing station, the average durations being for the observations at Gifu, Kagoshima and Fukuoka, respectively only 1.4, 2.0 and 0.2 seconds. Whether the duration of the preliminary tremor would actually vanish at the very *centre* (not the

1. At Gifu and Nagoya, much nearer to the origin, the durations of the preliminary tremor of the same earthquake were respectively 2 and 4 seconds.

epicentre) of an earthquake, is a problem which is very difficult to solve. But I believe such must, in some cases, be approximately true. The following are some of my own observations relating to the point in question.

8. On the 8th November, 1894, at 8.25 p. m., I experienced one of the after-shocks of the destructive Shonai Earthquake in the town of Fujishima, which is situated quite near to the epicentre of that earthquake. At the time, I was sitting quietly upstairs of a wooden two-storied house, and felt the shock as a sudden blow coming from below, accompanied by a loud noise, such as that caused by the falling of a heavy body on the ground. The motion consisted of a single principal vertical movement, followed by very feeble vibrations, the whole duration being about 30 seconds. Although the effect of the shock was strong enough to cause people to run out of doors, I observed the lamps suspended from the ceiling of my room remaining still and not thrown into oscillations. In this case, the shaking began abruptly and had no preliminary tremor, the origin of disturbance, which was evidently local, being quite near to the place of observation.

9. The observation at Midori. Soon after the great Mino-Owari Earthquake of the 28th October, 1891, a temporary seismological observatory was established at the village of Midori in the Néo-Valley, before referred to (§ 1), and a number of the after-shocks were seismographically registered.

It is to be noted that after the initial great earthquake the principal centre of seismic activity was not in the Néo-Valley, but to the south of it in the vicinity of Gifu. The phenomena of earthquake-sounds were, however, most frequent and intense in the Valley, the sounds being usually like that caused by the

falling of a heavy weight on the ground or by the discharge of a cannon at a distance.

The results of the seismographical observations at Midori, carried out between the 11th and the 28th November, 1891, may be summarised as follows:—Of the 18 earthquakes, whose motion was large enough to be distinctly measured, the strongest was that on the 28th November, 1891, at about 9.39 a.m., (No. 2, Table, § 2), of which the whole duration was 35 seconds and that of the preliminary tremor 4.2 seconds, the origin of this shock being much nearer to Gifu than to Midori. Four other earthquakes also originated at some distances from the observing station, and their movements consisted of comparatively slow undulations; the total duration varied between 7 and 43 seconds, and the maximum duration of the preliminary tremors was 2.7 seconds. The remaining 13 earthquakes were all small local shocks and consisted of very minute vibrations, of periods which varied between 0.023 and 0.17 seconds. All these shocks, whose duration varied between 0.9 and 4.3 seconds, had no preliminary tremor, but began at once with well-pronounced movements, except in one case in which the motion began with a well marked preliminary tremor of 0.1 second in duration.

It may be noted that the subterranean sound was perceived simultaneously with, or very shortly, say 1 or 2 tenths of a second, before the tremblings of the ground.

10. Let us put, for the sake of abbreviation, y =the duration, in seconds, of the preliminary tremor of an earthquake at a given station, whose distance from the origin of disturbance is x kilometres. Then, fig. 1, Pl. XIII, graphically illustrates the relation between x and y for the large distant earthquakes noticed

in § 6,¹ for No. 11, § 5, and for the Fukuoka Earthquake of the 12th August, 1898, as observed in Tokyo, § 4. The curve, $p q$, drawn through the mean positions, is approximately a straight line, whose equation is, by calculation, found to be

$$7.51 y = x - 24.9 \text{ km.} \quad (1)$$

The straight line, $p q$, cuts the abscissa axis at a point p ($x=24.9$ kilometres) instead of passing through the origin of coordinates. This may be due to the probable fact that the earthquake waves get weakened as they spread out from the origin, the very earliest portion becoming at great distances finally too small to affect the seismograph. For great earthquakes, whose origin is near to the observing station, say under 100 kilometres, such a dissipative effect would not much affect the duration of the preliminary tremor. These cases must be treated separately, taking into account, of course, the depths of the earthquake foci.

The duration of the preliminary tremor does not depend on the magnitude of the earthquake, which may be considered as represented by the extent of the area of disturbance. Thus, no difference of this kind is to be seen between the great Mino-Owari Earthquake and its after shocks, (See § 2). Again, the mean radii of propagation of the sensible shakings of the Mino-Owari Earthquake and the Rikuchu-Ugo Earthquake of the 31st August, 1891, (See No. 1 and No. 3, Table, § 6), were respectively 600 and 520 kilometres: the former earthquake was thus a little greater than the latter, but the durations of their preliminary tremors, observed in Tokyo, were respectively 37 and 56 seconds.

1. The focal depth is assumed to be negligible in comparison with the distance between the observing station and the origin of disturbance.

11. According to equation (1), which is to be regarded as applicable to great earthquakes at distances, say above 100 kilometres, from the observing station, the duration of the preliminary tremor is increased at the rate of 15 seconds per 100 kilometres of the distance y . This, if found to be always true, would enable us to estimate, from the diagram at any station by a sufficiently sensitive seismograph, the approximate distance of the origin of a shock. Or, if the seismographic records be simultaneously taken at two or more stations, we can, from the comparison of the durations of the preliminary tremors, easily fix the approximate position of the origin. I give next a few illustrations of the application of equation (1).

12. The durations of the preliminary tremors of the two large earthquakes of the 5th August, 1897, and of the 23rd April, 1898, recorded instrumentally at the Meteorological Observatory of Miyako (lat. $39^{\circ}38'$, long. $141^{\circ}59'$) were respectively 22 and 13 seconds, the corresponding durations in Tokyo being, as given in § 6, 45 and 54 seconds. According to equation (1), the distances of the origins of these two earthquakes from Miyako would respectively be about 190 and 120 kilometres, while the corresponding distances from Tokyo would be 360 and 430 kilometres. The positions of the origins as determined by the intersections of the circles drawn with radii equal to these distances about Miyako and Tokyo as centres are, as indicated in fig. 2, not very different from those to be inferred from the isoseismal lines.

13. The earthquake of the 8th June, 1898; 9.10 a.m. The earthquake was recorded by my Horizontal Pendulum at Miyako, the machine having been set up there just the day before. It was also signalled by the seismograph at the Miyako

Meteorological Observatory, but otherwise nowhere observed or reported. The duration of the preliminary tremor, as given by the Horizontal Pendulum diagram was 23 seconds, which, according to equation (1), would correspond to a distance of about 200 kilometres between the observing station and the probably suboceanic origin of the earthquake. In cases like this, it is impossible in any other way, to estimate the distance of the origin of disturbance.

14. The earthquake of the 7th October, 1898; 11.0.46 a.m. The earthquake shook moderately Oshima, Rikuoku, Rikuchu and Iburi. The duration of the preliminary tremor in Tokyo, as recorded by my Horizontal Pendulum was 82 seconds, while that at Miyako was 19.5 seconds. According to equation (1), the distances of the origin from Tokyo and Miyako would respectively be about 640 and 170 kilometres. The position of the origin determined by the intersection of the circles described about Tokyo and Miyako with radii respectively equal to these distances is indicated in fig. 3, it being nearly identical with that to be inferred from the isoseismal lines.

15. The fact that the duration at a given station of the preliminary tremor of an earthquake is nearly proportional to the distance of its origin from the station can be explained by assuming two sets of waves, which, originating simultaneously at the centre of disturbance, are propagated with different velocities. If V_1 denote the velocity of propagation of the small preliminary tremors, and if V_2 denote that of the principal waves of an earthquake, we find

$$\frac{1}{V_2} - \frac{1}{V_1} = \frac{x-24.9}{7.51 x}. \quad (2)$$

For the cases of the Mino-Owari Earthquake (No. 1, § 6) and the Hokkaido Earthquake (No. 2, § 6), we obtain :—

Mino-Owari Eqke. $V_1=2.1$ km. $V_2=1.6$ km.

Hokkaido Eqke. $V_1=2.3$ km. $V_2=1.8$ km.

It is, however, to be observed that equation (1) has been deduced from the observation of earthquakes, the distances of whose origins from the observing stations do not exceed 900 kilometres, and it would evidently be absurd to apply the same equation to cases of very distant earthquakes, for instance, those originating in Japan and observed in Europe. Such earthquakes give the high values for the transit velocity of 12 to 14 kilometres per second.

16. What was said in the preceding paragraphs seems to show the coexistence in earthquakes of two principal kinds of waves whose velocities of propagation are different. It must not, however, be supposed that the motion of an earthquake consists of only two kinds of waves. On the contrary, an earthquake motion consists, when the origin is not very far distant from the observing station, of several kinds of waves with different periods of vibration, ranging generally between a fraction of a second and several seconds. Short-period vibrations, which always occur most markedly at the beginning of the motion, gradually die away, leaving behind only the vibrations of long periods. Perhaps it may be that waves with different periods are propagated with different velocities.

Fig. 5 is a reproduction of the EW component diagram of the moderately strong earthquake of the 3rd April, 1898, recorded in Tokyo by my long-period Horizontal Pendulum Seismograph, the period of proper oscillation of whose horizontal

pendulum is 24 seconds. The length of the smoked paper wrapped round a drum, on which the record was taken, is 745 mm., the drum making one complete revolution once in 70 seconds. The proper motion of the horizontal pendulum is not shown in the diagram, and therefore all the waves are to be regarded as indicating real earthquake movements. The motion was here recorded only as far as the 210th second from the commencement, but the real duration was much longer. According to the diagram, there were the following four kinds of waves superposed one upon the others:—

1. Waves, whose average period was 0.36 second, and whose maximum range was 0.6 mm.
2. Waves, whose average period was 0.88 second, and whose maximum range of motion was 0.6 mm.
3. Waves, whose average period was 1.5 seconds, and whose maximum range of motion was 0.9 mm.
4. Waves, whose average period was 3.4 seconds, and whose maximum range of motion was 1.7 mm.

This earthquake, whose origin was about 100 kilometres west of Tokyo, was in the NS component recorded by the Horizontal Pendulum. According to the diagram, the total duration was about 20 minutes, the average period of the principal undulations, whose maximum motion was 2.2 mm., being about 6.3 seconds. The duration of the preliminary tremor was 15 seconds. (In fig. 4 is given the earlier portion of the diagram).

November, 1898.

Seismological Institute, Tokyo.



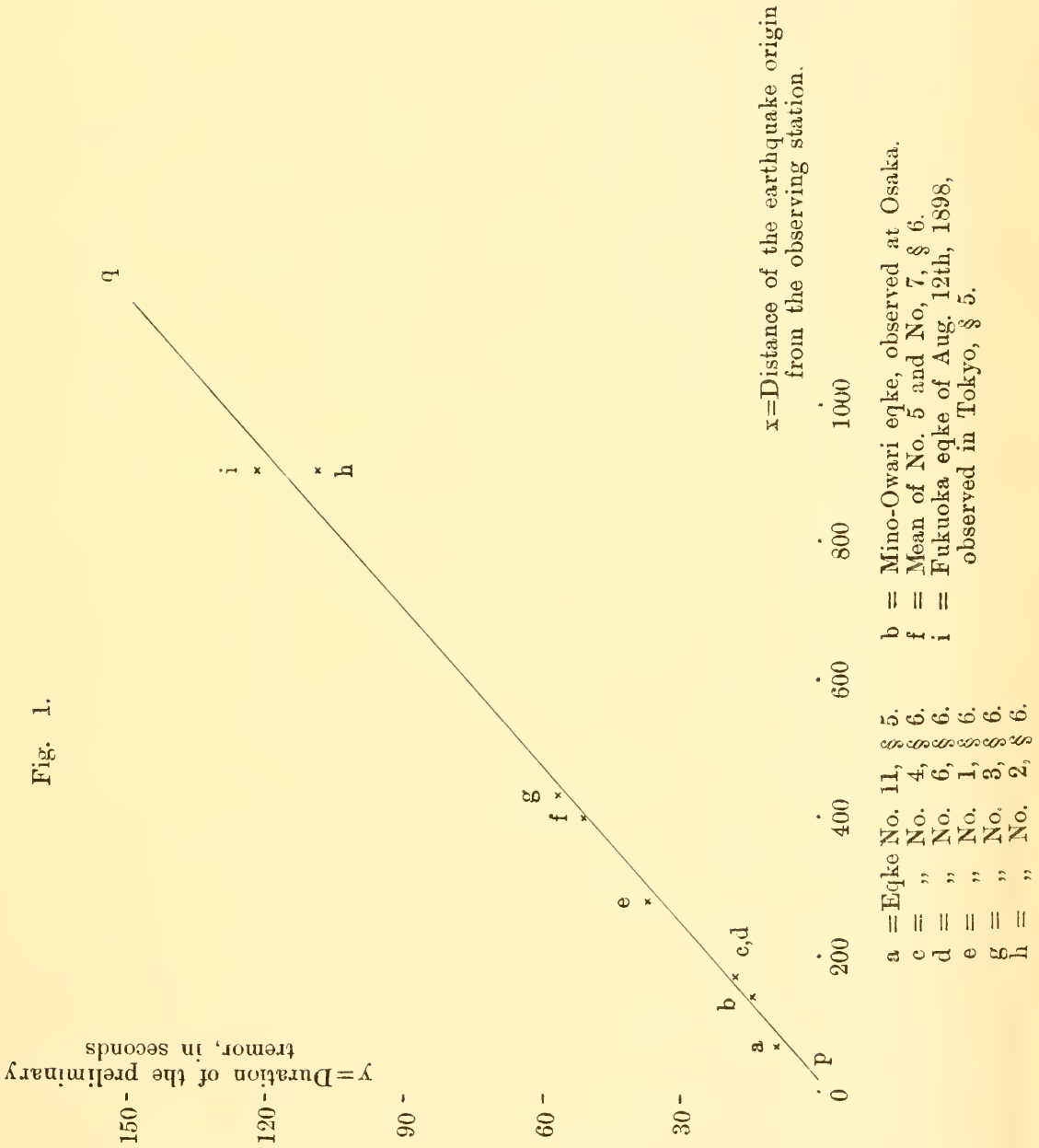
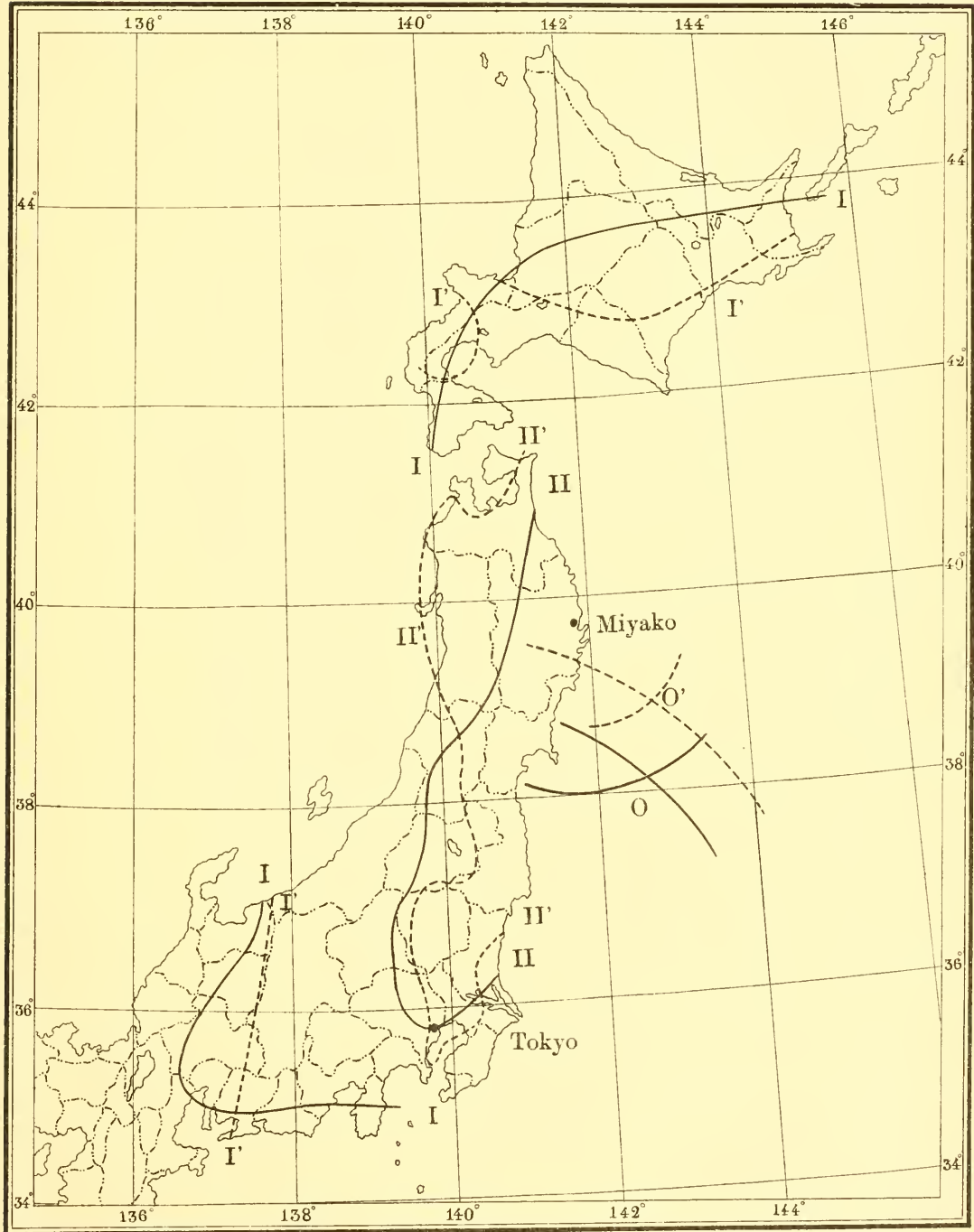


Fig. 2. The Earthquakes of Aug. 5th, 1897, and of April 23rd, 1898.



----- Boundary of provinces.

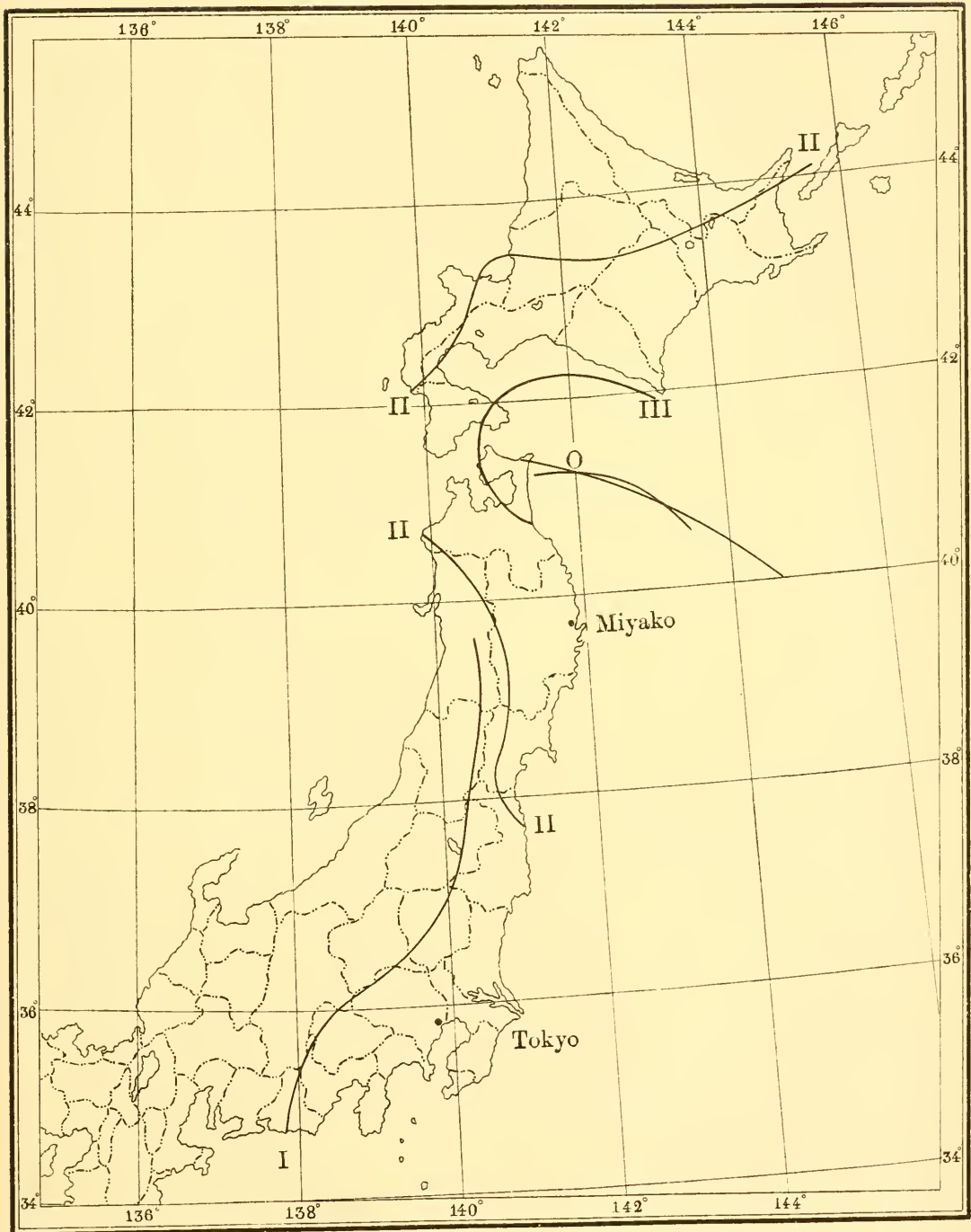
Full curves, I and II, refer to the eqke of Aug. 5th, 1897, and dotted curves, I' and II', to that of April 23rd, 1898.

I, I', Boundary of the area of slight motion.

II, II', " " " " " strong " "

O and O' indicate the approximate positions of the eqke origins.

Fig. 3. The Earthquake of Oct. 7th, 1898.



--- Boundary of provinces

I. Boundary of the area of slightest motion.

II, " " " " " slight "

III, " " " " " strong "

O indicates the approximate position of the earthquake origin.

Fig. 4. The Earthquake of April 3rd, 1898; NS component. (Recorded by Omori's Horizontal Pendulum.) Multiplication 10 times.

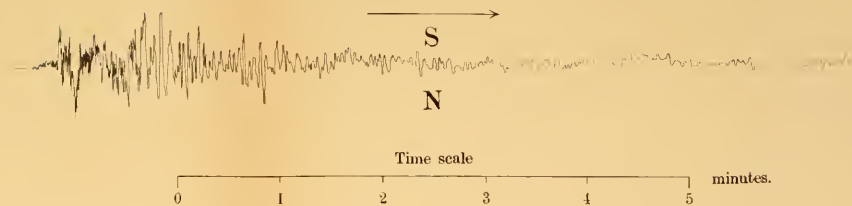
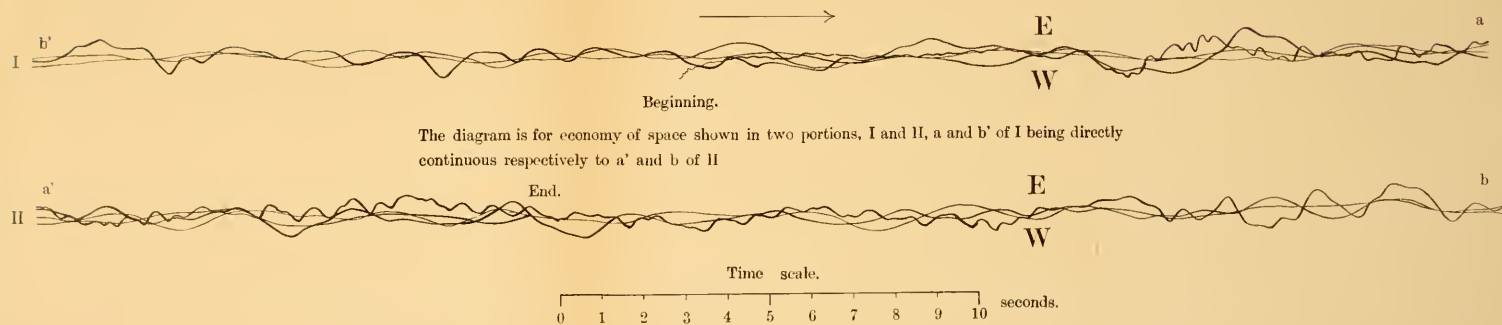


Fig. 5. The Earthquake of April 3rd, 1898; EW component. (Recorded by the long-period Horizontal Pendulum Seismograph.) Multiplication $6\frac{1}{2}$ times.



Earthquake Measurement at Miyako.

By

F. Omori, D. Sc.,

Professor of Seismology, Tokyo Imperial University,

and

K. Hirata,

Director of the Meteorological Observatory of Miyako.

With Plates XVII—XXIII.

1. The Meteorological Observatory of Miyako (lat. $39^{\circ}38'$, long. $141^{\circ}59'$) is situated on a small promontary of palaeozoic rocks, 30 m. in height, which separates the two towns of Miyako and Kuwagasaki. As, besides, the prevailing formation in this part of the Pacific coast of the Main Island is the granite, the following seismographical observations at Miyako are to be regarded as good illustrations of earthquake measurements in a rocky district.

The seismograph used was one of the Gray-Milne type, which records, by means of a pair of horizontal pendulums and compensated vertical springs, the earthquake motion in three rectangular components on a smoked paper wapped round a revolving drum, started, as usual, on the occurrence of an earthquake by a sensitive electric contact-maker.

2. There were 27 earthquakes, which gave diagrams sufficiently large and distinct to be measured. Their dates and time¹ of occurrence are given in the following table:

1. The time is given in the First Normal Japan Time, namely, that of longitude 135° E.

List of earthquakes observed at Miyako.

No.	Date.			Time of occurrence at Miyako.			
				h.	m.	s.	
1	15th	June,	1896.	7.	32.	30	p. m.
2	17th	"	"	0.	46.	25	p. m.
3	31st	August,	"	4.	42.	15	p. m.
4	"	"	"	5.	09.	55	p. m.
5	"	"	"	7.	20.	52	p. m.
6	1st	September,	"	2.	55.	15	p. m.
7	5th	"	"	11.	09.	25	p. m.
8	7th	February,	1897.	4.	35.	30	p. m.
9	20th	"	"	5.	49.	00	a. m.
10	27th	March,	"	7.	46.	43	p. m.
11	30th	April,	"	5.	51.	15	a. m.
12	18th	June,	"	1.	18.	05	p. m.
13	5th	August,	"	9.	10.	47	a. m.
14	7th	"	"	9.	09.	07	p. m.
15	16th	"	"	4.	53.	03	p. m.
16	23rd*	"	"	9.	32.	56	
17	27th	"	"	1.	06.	31	a. m.
18	2nd	October,	"	9.	42.	03	p. m.
19	4th	December,	"	9.	19.	21	a. m.
20	8th	"	"	5.	20.	48	p. m.
21	23rd	"	"	0.	29.	16	p. m.
22	26th*	"	"	3.			p. m.
23	31st	"	"	11.	50.	28	p. m.
24	23rd	April,	1898.	8.	34.	13	a. m.
25	19th	May,	"	9.	50.	40	a. m.
26	31st	"	"	1.	03.	22	a. m.
27	3rd	June,	"	3.	22.	10	p. m.

Besides these 27 earthquakes, four very small shocks, whose exact dates are missing, have also been measured, thus making up a total of 31 earthquakes.

*The dates of eqkes. Nos. 16 and 22 are not quite certain, there being no report in the Central Meteorological Observatory relating to these two shocks.

As typical specimens, are given in figs. 1, 2, and 3, Pl. XVII, the seismographic diagrams of three earthquakes, Nos. 2, 3, and 11. Further, in figs. 4, 5, 6, 7 and 8 are given, for the sake of reference, maps illustrating the areas of disturbance of seven earthquakes, Nos. 3 and 20, 8, 11, 10, and 1 and 2.

3. In the following description of the seismographic diagrams, the terms *preliminary tremor*, *principal portion* and *end portion* have been employed to designate three successive stages of an earthquake motion, defined as follows:

The *preliminary tremor* of an earthquake denotes the introductory movements of very small amplitude, their period being generally short.

The *principal portion* denotes the most active part of an earthquake, which follows the preliminary tremor and which consists of movements of larger amplitude.

The *end-portion* denotes the feeble finishing part of an earthquake, which follows the principal portion.

It is here to be noted that the limits of the principal portion are sometimes very well marked, but in other cases more or less indefinite.

Again the terms, *ripples* and *slow undulations*, have been used to denote respectively those quick earthquake vibrations, whose periods are mere fractions of a second, and those comparatively gentle movements, whose periods are much longer than those of the former.

The abbreviations used in this paper are as follows:—

H.M. denotes Horizontal Motion.

V.M. ,, Vertical ,,

2*a* ,, Range of ,,

T	denotes	Period of Vibration. ¹
(EW)	„	East-West Component.
(NS)	„	North-South „
(V)	„	Vertical „

4. Eqke. No. 1. The 15th June, 1896 ; 7.32.30 p. m. Intensity,² *weak*.

The seismographic record evidently indicates a distant shock, the motion consisting entirely of slow undulations, free from superposed ripples. According to Mr. T. Iki, who investigated the fearful sea-waves caused by this earthquake, the origin of disturbance was situated at a point, long. $144^{\circ}30'$ E, lat. 39° N, that is to say, at about 240 km. ESE of Miyako. Judging, however, from the isoseismal lines,³ the origin of the earthquake seems to be situated at about 170 km. ESE of Miyako. (See fig. 8).

The H.M. was four to six times greater in the EW than in the NS component, the V.M. being very small. The motion was, therefore, practically horizontal and in the EW direction, there being occasional fluctuations in the range of motion. The maximum $2a$ was 4.0 mm. As the rotation of the record-receiving drum was unfortunately irregular, we can not measure exactly the period of vibration. The duration was probably not less than 5 minutes.

5. Eqke. No. 2. The 17th June, 1896 ; 0.46.25 p. m. Intensity, *slight*. (See fig. 1). The origin of the earthquake was probably close to that of Eqke. No. 1. (See fig. 8).

1. In this paper, the *period* signifies always the *complete period*.

2. The *intensity* of an earthquake is, in this paper, indicated as *strong*, *weak* or *slight*. A *slight* shock is one which is very feeble and just strong enough to be felt; a *weak* shock is one whose motion is well-pronounced but not so severe as to cause general alarm; and finally a *strong* shock is one which is sufficiently strong to knock down some furnitures, to cause people to run out of doors, etc.

3. All the distances between the origins of disturbance and Miyako, given in §§ 4-34, have been estimated from the isoseismal lines of the respective earthquakes.

The motion, which, as in No. 1, consisted of slow undulations almost perfectly free from superposed ripples, was about $2\frac{1}{2}$ times greater in the EW than in the NS component, the V.M. being also present. The duration of the H.M., as well as that of the V.M. was 56 seconds.

The *preliminary tremor*, whose duration was 13 seconds, consisted of very small slow undulations of an average period of 0.86 second.

The maximum vibration, whose period was 1.7 seconds, and which occurred at the beginning of the *principal portion*, consisted of the following two displacements :

(First motion): 2.8 mm. towards E, 0.9 mm. towards N and slightly upwards. Resultant $2a=2.9$ mm., direction $E\ 25^\circ N$.

(Second motion): 3.8 mm. towards W, 1.4 mm. towards S, and 0.3 mm. downwards. Resultant $2a=4.1$ mm., direction $W\ 25^\circ S$, the angle of emergence $= 4^\circ$.

The average period of the seven small vibrations, which followed the maximum motion, was in the (EW) 0.82 second, and in the (NS) 0.77 second. At about 21 seconds from the commencement there was a second maximum epoch, which consisted of three nearly equal undulations of an average period of 1.4 seconds, the two displacements of the first vibration being as follows :—

(First motion): 0.7 mm. towards E, 0.2 mm. upwards. Resultant $2a=0.7$ mm., direction E, the angle of emergence $= 16^\circ$.

(Second motion): 1.1 mm. towards W, 0.3 mm. downwards. Resultant $2a=1.1$ mm., direction W, the angle of emergence $= 13^\circ$.

The third maximum epoch occurred at about 27 seconds from the beginning, the average period of vibration being 1.2 seconds in the (EW) and 1.0 second in the (NS).

The mean of the above three angles of emergence is 11° , and it will be observed that the direction of motion dipped towards W instead of towards E, where was situated the origin of the disturbance. Of course it is out of question to inquire into the relation between the direction of motion and the position of the origin in cases like the present, where the intensity of earthquake motion at the observing station is already very feeble.

6. Eqke. No. 3. The 31st August, 1896; 4.42.15 p.m. Intensity, *strong*. This earthquake was strongly felt in the central and western portions of the Province of Ugo and Rikuchū, and was one of the fore-shocks of the destructive earthquake, which took place on the same day at 5.9.55 p.m. Judging from the isoseismal lines (fig. 4), the epicentre was situated at about 100 km. S 80° W of Miyako.

The seismographic diagram (fig. 2) shows a considerable amount of horizontal and vertical motion, which consisted of ripples superposed on slow undulations. The H.M. was more than four times greater in the (EW) than in the (NS). The duration of the H.M. was 73 seconds, and that of the V.M. was 89 seconds.

The *preliminary tremor*, whose duration was 10 seconds, consisted of ripples of the following elements :—

	(EW)	(NS)	(V)
Maximum $2a$	1.0 mm.	1.2 mm.	0.2 mm.
Average period	0.07 second	(not clear)	0.06 second.

These ripples were superposed on slow undulations, whose maximum $2a$ was 1.4 mm. (period 1.4 seconds) in the (EW), very small in the (NS), and 0.2 mm. in the (V).

The *principal portion*, whose duration was 4 seconds, consisted essentially of three large well-defined vibrations of an average period of 1.0 second, the maximum horizontal motion (period 0.94 second), being composed of the following two displacements :

(First motion): $2a=9.0$ mm., direction S 79° W.

(Second motion): $2a=9.0$ mm., direction N 79° E.

The succeeding vibrations were executed also in nearly the same direction, that is, ENE—WSW, the direction of motion, however, gradually changing as we pass into later and smaller vibrations. Thus the second vibration after the maximum consisted of the following two displacements :

(First motion): $2a=5.0$ mm., direction S 66° W.

(Second motion): $2a=3.1$ mm., direction N 46° E.

The principal vibration of the V.M., whose average period was 0.9 second, occurred simultaneously, but did not synchronize, with those of the H.M. The maximum $2a$ of the V.M. was 1.3 mm., its period being 0.9 second.

In the *end portion*, the average period of ripples was 0.09 second in the (EW), and 0.06 second in the (V).

It may here be noted that the direction of the maximum vibration, namely S 79° W—N 79° E, pointed exactly towards the epicentre of the earthquake.

7. Eqke. No. 4. The 31st August, 1896; 5.9.55 p.m. Intensity, *very strong*. This was the great earthquake, which caused much destruction in the eastern part of the Province of Ugo and the western part of the Province of Rikuchu, the origin being at about 100 km. S 80° W of Miyako.

The duration of the H.M., as well as that of the V.M. was 100 second.

In the *preliminary tremor*, whose duration was 5.2 seconds, the amplitude of motion was much greater in the (EW) and the (V) than in the (NS), the maximum ranges being 5.4 mm. in the (EW), 1.4 mm. in the (NS), and 3.5 mm. in the (V).

At about 4 seconds from the beginning, there were two vibrations of the period of 0.8 second each, which consisted of the following four displacements :

{(First motion): 2.6 mm. towards W, 2.1 mm. downwards.
{Resultant $2a=3.3$ mm., the angle of emergence = 39° .

{(Second motion): 1.7 mm. towards E, 3.5 mm. upwards.
{Resultant $2a=3.9$ mm., the angle of emergence = 64° .

{(Third motion): 2.8 mm. towards W, 3.4 mm. downwards.
{Resultant $2a=4.4$ mm., the angle of emergence = 50° .

{(Fourth motion): 4.2 mm. towards E, 2.8 mm. upwards.
{Resultant $2a=5.1$ mm., the angle of emergence = 34° .

It is to be remarked that the above four angles of emergence relate to the vibrations in the preliminary tremor, and are probably very different from those in the principal portion of the shock, the mean angle of emergence of 47° giving obviously a too great depth of the earthquake focus.

The *principal portion*, whose duration was 26 seconds, was unfortunately vitiated by the large oscillations of the seismograph pendulums. The elements of the ripples have, however, been measured and found to be as follows :—

	(EW)	(NS)	(V)
maximum $2a$	>3.4 mm.	3.4 mm.	(obscure)
average period	0.088 second	0.085 second	0.064 second.

8. Eqke, No. 5. The 31st August, 1896; 7.20.52 p. m. Intensity, *weak*. The origin of the earthquake was evidently in the vicinity of the observing station, the V.M. existing to a proportionally large amount. Owing, however, to the irregular distribution of the intensity of motion, it is difficult to determine exactly the position of the epicentre.

The duration of the H.M., as well as that of the V.M. was 50 seconds.

The *preliminary tremor*, whose duration was 5.7 seconds, consisted of very fine ripples of an average period of 0.054 second in the (EW), and 0.043 second in the (NS); these being superposed on slow undulations of an average period of 0.86 second in the (EW), and 0.87 second in the (NS).

The preliminary tremor was abruptly followed by the *principal portion*, whose H.M. was much greater in the (NS) than in the (EW). The maximum vibration, whose period was 0.56 second, consisted of the following two displacements:

{(First motion). 1.2 mm. towards S, 0.6 mm. towards E.
{Resultant $2a=1.3$ mm., direction S 30° E.

{(Second motion). 2.1 mm. towards N, 0.6 mm. towards W.
{Resultant $2a=2.2$ mm., direction N 20° W.

The mean direction of motion was thus S 25° E—N 25° W.

The maximum V.M., which did not perfectly synchronise with the H.M., was 0.3 mm., its period being 0.53 second.

The average period of the ripples in the *principal portion* was 0.054 second in the (EW), 0.056 second in the (NS), and 0.055 in the (V); these being superposed on the slow undulations of an average period of 0.68 second in the (EW), 0.58 second in the (NS), and 0.32 second in the (V).

9. Eqke. No. 6. The 1st September, 1896 ; 2.55.15 p. m. Intensity, *slight*. This was one of the after-shocks of the eqke. No. 4, the origin being probably situated in the same position as that of the latter.

The duration of the H.M., as well as that of the V.M., was 48 seconds.

The motion was much greater in the (EW) than in the (NS), and consisted of very small ripples superposed on slow undulations, whose maximum motion was 0.4 mm. in the (EW), 0.1 mm. in the (NS), and 0.14 mm. in the (V). As the rotation of the record-receiving drum was unfortunately not perfectly good, the period can not be determined accurately.

10. Eqke. No. 7. The 5th September, 1896 ; 11.9.25 p. m. Intensity *strong*. The origin of the earthquake was in the Pacific, probably at about 130 km. ENE of Miyako.

The duration of the H.M. as well as that of the V.M. was 35 seconds. The motion, in which V.M. was present to a proportionally large amount, was active for the first 5 seconds and then became abruptly small. The maximum motion of the ripples, which were superposed on slow undulations, was 3.6 mm. in the (EW), 3.0 mm. in the (NS), and 0.4 mm. in the (V).

As the rotation of the record-receiving drum was unfortunately not perfectly regular, it is impossible to estimate accurately the periods of vibration.

11. Eqke. No. 8. The 7th February, 1897 ; 4.35.30 p. m. The earthquake consisted of two shocks with a time interval between them of about 1 minute, the intensity of the first shock being *weak*, and that of the second being *strong*. In these two shocks, the maximum motions in the \perp (EW) were respectively 4 and $2\frac{3}{4}$ times greater than those in the (NS), the V.M. being

also present to a proportionately large amount. The character of motion in each earthquake was very simple, the *preliminary tremor* being followed abruptly by a large vibration.

The area of strong earthquake motion was an oblong ellipse, whose major axis, about 320 kilometres in length, was in the direction of NEN—SWS, and the shocks were probably caused by the formation of a long fissure or dislocation at a great depth under the mountain chains forming the back-bone of the northern part of the Main Island. The epicentre, or the central point of the meizoseismal area, was situated at about 130 km. S 60° W of Miyako. (See fig. 5).

The maximum range of motion of the first shock was 5.4 mm. in the (EW), 2.0 mm. in the (NS), and 0.5 mm. in the (V).

The maximum motion of the second shock was as follows :

26.0 mm. towards W, 9.6 mm. towards S, 3.5 mm. downwards. Resultant $2a=28.0$ mm., direction S 65° W, the angle of emergence= 7.2° .

This maximum displacement was preceded by the following next-maximum movements :—

(First motion). 4.2 mm. towards W, 3.5 mm. towards S, 0.5 mm. downwards. Resultant $2a=5.5$ mm., direction SW, the angle of emergence= 5.2° .

(Second Motion). 14.4 mm. towards E, 8.4 mm. towards N, 2.3 mm. upwards. Resultant $2a=17.0$ mm., direction N 55° E, the angle of emergence= 7.8° .

As the rotation of the record-receiving drum was unfortunately irregular, the periods of particular waves can not be accurately determined. But, judging from the number of the superposed ripples, the period of the principal vibration was

probably about 1.2 seconds. The movements, which followed the principal motion, were very small.

The direction of motion, averaged from the three chief displacements of the second shock given above was $S\ 55^{\circ}\ W$ — $N\ 55^{\circ}\ E$, pointing very nearly towards the centre of the meizoseismal area. The greatest motion was in this case directed towards the origin.

Adopting the mean angle of emergence of 6.7° , which, as it relates to well-defined maximum vibrations, can not but be regarded as real, the depth of the earthquake focus comes out to be 16 km.¹

12. Eqke. No. 8'. This was a very small shock, whose date is not given, but which was recorded on the same smoked paper as eqke. No. 8. Intensity, *very slight*. The motion, which consisted entirely of ripples, was chiefly in the (EW) and (V), and was practically zero in the (NS), the maximum range of motion being 0.4 mm. in the (EW), 0.0 mm. in the (NS), and 0.1 mm. in the (V).

13. Eqke. No. 9. The 20th February, 1897 ; 5.49.0 a. m. Intensity, *very strong*. This earthquake was very extensive in area and caused some damage in the provinces of Rikuzen and Rikuchu, the origin being situated probably at about 220 km. SE of Miyako.

The motion was much greater in the (EW) than in the (NS), a considerable amount of the V.M. being also present. The record was, however, imperfect, all the three writing pointers having been thrown out of the record-receiving smoked paper at 18.6 seconds from the beginning.

1) The depths of earthquake foci have in this paper been calculated by the usual method of the angle of emergence.

14. Eqke. No. 10. The 27th March, 1897 ; 7.46.43 p. m. Intensity, *slight*. The origin was situated probably at about 70 km. NE of Miyako. (See fig. 7).

The motion, which consisted of regular ripples, was larger in the (EW) than in the (NS). The duration of the H.M. was 80 seconds, and that of the V.M. was 47 seconds.

The *preliminary tremor*, whose duration was 4.2 seconds, consisted in each component of vibrations of an average period of 0.078 second.

The transition from the *preliminary tremor* to the *principal portion* of the shock was marked by the appearance of slow undulations with minute ripples superposed, which formed the apparent continuation of those in the preliminary tremor, but whose period became slightly longer than before. The average period of the ripples in the *principal portion*, whose duration was about 24 seconds, was 0.100 second in the (EW), 0.093 second in the (NS), and 0.091 second in the (V); the maximum range of these vibrations being 0.39 mm. in the horizontal, and 0.08 mm. in the vertical component.

From about 29 seconds after the beginning, the period of ripples became again shorter, being practically the same as that in the preliminary tremor, namely, 0.076 second in the (EW).

The elements of the slow undulations were as follows :—

	(EW)	(NS)	(V)
Maximum $2a$:	0.4 mm.	0.3 mm.	0.2 mm.
Average period :	1.1 seconds	(obscure)	1.5 seconds.

15. Eqke. No. 11. The 30th April, 1897 ; 5.51.15, a. m. Intensity, *weak*. This was a small local shock, whose origin was situated probably at about 60 km. NE of Miyako. (See fig. 6).

The duration of the H.M. was 42 seconds, and that of the V.M. was 33 seconds.

The *preliminary tremor*, whose duration was 2.6 seconds, consisted of ripples of an average period of 0.080 second in the (EW), 0.073 second in the (NS), and 0.065 second in the (V). (For the diagram, See fig. 3).

The *principal portion*, which lasted for about 0.7 second, consisted of vibrations of an average period of 0.12 second in the (EW), 0.12 second in the (NS), and 0.13 second in the (V). The first prominent displacement and the two succeeding ones were as follows:—

(First motion). 0.8 mm. towards W, 0.62 mm. towards S, 0.2 mm. upwards. Resultant $2a=1.0$ mm., direction $W\ 43^\circ S$, the angle of emergence $= 12^\circ$.

(Second motion). 1.2 mm. towards E, 1.0 mm. towards N, 0.2 mm. downwards. Resultant $2a=1.6$ mm., direction NE, the angle of emergence $= 7^\circ 2$.

(Third motion). 1.2 mm. towards W, 1.0 mm. towards S, 0.2 mm. upwards. Resultant $2a=1.6$ mm., direction SW, the angle of emergence $= 7^\circ 2$.

The mean direction of motion deduced from the above three displacements is NE—SW, while the corresponding angle of emergence $= 9^\circ$. The depth of the earthquake focus comes out to be 10 km.

The *end portion* of the earthquake consisted of ripples, whose average period was a little shorter than that in the principal portion. Thus, measuring from about 3.3 seconds after the beginning, when the principal portion ceased, the average period was 0.078 second in the (EW), 0.078 second in the (NS), and 0.067 second in the (V). Again, measuring from 7.8 seconds

after the beginning, the average period was 0.094 second in the (EW), and 0.081 second in the (NS). There were also some slight traces of slow undulations.

16. Eqke. No. 12. The 18th June, 1897; 1.18.5 p.m. Intensity, *strong*. The origin was evidently in the vicinity of the observing station, probably near to the sea-coast, at about 90 km. SE of Miyako.

The duration of the H.M. was 50 seconds. The V.M. was evidently very considerable, but was unfortunately not recorded, the pointer of the vertical motion seismograph having been thrown off the record-receiver immediately after the termination of the preliminary tremor.

The *preliminary tremor*, whose duration was 8.5 seconds, consisted of ripples of the following elements.

	(EW)	(NS)	(V)
Maximum $2a$:	0.12 mm.	0.3 mm.	very small.
Average period:	0.083 second	0.078 second	0.064 second.

It is to be remarked that during the preliminary tremor, the motion was much greater in the horizontal than in the vertical component, and again about twice as great in the (NS) as in the (EW). Further, the motion remained nearly constant throughout this epoch, the amplitude being not smaller in the beginning than in the ⁷later portion.

In the *principal portion*, whose duration was 9 seconds, the motion was about twice as great in the (EW) as in the (NS), the average period being longer than that in the preliminary tremor, namely, 0.11 second in the (EW), and 0.10 second in the (NS). The most active movement was limited to the first 2.3 seconds of the principal portion, and the mean direction

of motion, whose maximum $2a$ was 7.4 mm., was N 60° E—S 60° W.

In the *end portion*, the period became again a little shorter.

17. Eqke. No. 13. The 5th August, 1897; 7.10.47 a. m. Intensity, *weak*. This extensive earthquake originated under the ocean, probably at 220 km. SE of Miyako, the epifocus being evidently linear and running nearly parallel to the coast.

The duration of the H.M. was 200 seconds, and that of the V.M. was 150 seconds. In the preliminary tremor, the motion was equally pronounced in the two horizontal components; but in the principal and the end portions, it was much larger in the (EW) than in the (NS), and consisted of small ripples superposed on slow undulations indicative of a distant origin.

The *preliminary tremor*, whose duration was 22 seconds, consisted of ripples of an average period of 0.07 second in the (EW) and 0.06 second in the (NS); these ripples being superposed on slow undulations of an average period of 0.8 second in the (NS).

The *principal portion*, consisted of ripples whose maximum $2a$ was 0.4 mm. in each component, and whose average period was 0.087 second in the (EW), 0.080 second in the (NS), and 0.075 second in the (V). The period of the ripples remained nearly constant throughout the duration of the shock, these being superposed on slow undulations of an average period of 0.82 second in the (NS), (uncertain in the (EW)), and 0.7 second in the (V). One of the largest of these slow undulations in the (NS) had the maximum $2a$ of 1.8 mm., its period being 0.74 second. The corresponding movement in the (EW) was

probably still greater, but was unfortunately obscured by the proper oscillations of the pendulum. The corresponding maximum vertical motion was 0.57 mm., its period being 0.6 second.

There existed in the (EW) still slower undulations of an average period of 1.7 seconds, the maximum motion of this kind being $2a=1.6$ mm., period=1.8 seconds.

18. Eqke. No. 14. The 7th August, 1897; 9.9.7 p.m. Intensity, *slight*. The earthquake had its origin probably at nearly the same locality as earthquake No. 13, the disturbed area being, however, smaller in this case.

The duration of the H.M. was 150 seconds, and that of the V.M. was 60 seconds, the character of the motion being gentle and indicative of a distant origin.

The *preliminary tremor*, whose duration was 23 seconds, consisted of fine ripples of an average period of 0.08 second in the (EW), which were prominent only for the first 5.8 seconds, becoming thereafter very small.

The *principal portion*, in which the motion was greater in the (EW) than in the (NS), consisted of slow undulations of an average period of 1.6 seconds in the (EW), 1.0 second in the (NS), and 0.8 second in the (V), these being in the earlier portion of the epoch superposed upon by traces of ripples. The maximum horizontal range of motion of slow undulations was $2a=0.9$ mm. toward NE, $T=1.0$ second; and the corresponding maximum vertical motion was $2a=0.12$ mm., $T=0.78$ second.

19. Eqke. No. 15. The 16th August, 1897; 4.53.3 p.m. Intensity, *weak*. The origin of this earthquake was probably a little nearer to the coast than that of the two preceding ones.

The duration of the H.M. was about 140 seconds, and that of the V.M. was 70 seconds, the character of motion being mild

and indicative of a rather distant origin. In the *principal portion*, the amplitude was much greater in the (EW) than in the (NS).

The *preliminary tremor*, whose duration was 16 seconds, consisted of ripples of an average period of 0.085 second in the (EW), and 0.08 second in the (NS). These movements, whose maximum $2a$ was 0.12 mm. in each horizontal component, were superposed on slow undulations of an average period of 1.0 second in the (NS). The transition from the preliminary tremor to the *principal portion* was marked in the (NS) by the slow undulations becoming more prominent. The (EW) was unfortunately confused by the proper oscillations of the pendulum.

The *principal portion*. The maximum motion of the ripples, which, including the preliminary tremor, lasted for 70 seconds, was

(H.M.) $2a=0.64$ mm., $T=0.12$ second,

(V.M.) very small;

their average period, which remained nearly constant throughout the earthquake, being 0.081 second in the (EW), and 0.083 second in the (NS). The maximum slow undulations were the following :

(H.M.) $2a=2.8$ mm., $T=1.6$ seconds.

(V.M.) $2a=0.4$ mm., $T=0.7$ second.

20. Eqke. No. 15'. The date is not given, but the record was taken on the same smoked paper as Eqke. No. 15. Intensity, *very slight*. The earthquake was evidently a small local one, and the motion, whose duration was 23 seconds consisted entirely of minute ripples, the V.M. being practically zero.

The *preliminary tremor*, whose duration was 7.8 seconds, was composed of vibrations of an average period of 0.078 second in the (EW), and 0.074 second in the (NS).

The initial movements ceased almost completely a short time before the appearance of the *principal portion*, whose maximum $2a$ was 0.2 mm., and whose average period was 0.084 second in each component. It is here to be remarked that in cases of small shocks like the present, there often exists no prominent maximum motion, a great number of vibrations having nearly the same amplitude.

21. Eqke. No. 16. The 23rd August, 1897; 9.32.55. Intensity, *weak*. The date is possibly erroneous, there being in the Central Meteorological Observatory no report relating to this earthquake. The duration of the H.M. was 100 seconds, and that of the V.M., 70 seconds.

The *preliminary tremor*, whose duration was 11 seconds, consisted of fine ripples of an average period of 0.090 second in the (EW), 0.083 second in the (NS), and 0.086 second in the (V). It is to be remarked that these ripples were greatest in the (NS) and smallest in the (V), the maximum $2a$ being 0.24 mm. in the (EW), 0.4 mm. in the (NS), and 0.05 mm. in the (V).

The *principal portion*, which was well marked off by greater amplitude and larger period, lasted for 9.3 seconds, the motion being especially active during 4 seconds at the middle of this epoch. The average period of these principal vibrations, whose general direction was WSW—ENE, was 0.11 second in each horizontal component; the maximum motion being

$$\text{(H.M.) } 2a=2.1 \text{ mm. } T=0.14 \text{ second,}$$

$$\text{(V.M.) } 2a=0.3 \text{ mm.}$$

The average period of the ripples occurring immediately after the most active portion of the shock was 0.10 second in the (EW), 0.09 second in the (NS), and 0.10 second in the (V).

In the *end portion*, the average period of ripples was 0.10 second in each horizontal component.

The ripples were superposed on slow undulations of an average period of 1.7 seconds in the (EW), 1.0 second in the (NS), and 0.8 second in the (V).

22. Eqke. No. 16'. The date is not given, but the record was taken on the same smoked paper as Eqke. No. 16. Intensity, *very slight*. The duration was 23 seconds, there being no V.M. The shock consisted of very fine ripples, which were greater in the (EW) than in the (NS). There was no preliminary tremor, and the motion was greatest at the commencement, thence gradually diminishing. The average period was 0.082 second in the (EW), and 0.084 second in the (NS).

23. Eqke. No. 16''. The date is not given, but the record was taken on the same smoked paper as Eqke. No. 16. Intensity, *very slight*. The duration was 8.5 seconds, there being no V.M. The average period was 0.09 second in the (EW).

24. Eqke. No. 17. The 27th August, 1897; 1.6.31 a.m. Intensity, *slight*. The origin was situated probably at 160 km. SE of Miyako, and the motion consisted of slow undulations, which were perfectly free from superposed ripples, evidently indicating a very distant origin.

The duration of the H.M. was 70 seconds, and that of the V.M., 39 seconds.

The *preliminary tremor*, whose duration was 21 seconds, was succeeded by the maximum motion of the following elements :

(H.M.) $2a=1.0$ mm., $T=1.2$ second, direction N 60° W.

(V.M.) $2a=0.1$ mm.

The average period was 1.6 seconds in the (EW), and 0.8 second in the (NS).

25. Eqke. No. 17'. The date is not given, but the record was taken on the same smoked paper as Eqke. No. 17. Intensity, *very slight*. The duration was 26 seconds, there being no V.M. The average period of vibrations, whose maximum $2a$ was 0.1 mm. in each horizontal component, was 0.09 second in the (EW) and also 0.09 second in the (NS).

26. Eqke. No. 18. The 2nd October, 1897; 9.42.3 p. m. Intensity, *strong*. This was an extensive earthquake, whose origin was probably situated at about 150 km. ESE of Miyako. The duration of H.M. was 110 seconds.

The *preliminary tremor*, whose duration was 12.5 seconds, consisted of small ripples of an average period of 0.07 second in each horizontal component. These movements, whose maximum $2a$ was 0.2 mm. in each horizontal component, were superposed on slow undulations of an average period of 0.9 second in each horizontal component.

The *principal portion* lasted for 13.6 seconds, and consisted of ripples, whose average period was 0.09 second in the (EW), and 0.08 second in the (NS). The V.M. was confused by the proper pendulum oscillations. The maximum horizontal ripple was $2a=1.5$ mm., $T=0.12$ second, direction $S 75^\circ W$. The ripples were superposed on slow undulations of an average period of 1.3 second in the (EW). 1.0 second in the (NS), and 1.0 second in the (V); the maximum motion of this kind being

(H.M.) $2a=2.3$ mm., $T=1.0$ second, direction $S 55^\circ W$.

(V.M.) $2a=1.4$ mm.

The *end portion* consisted of ripples of an average period of 0.06 second in each horizontal component; these being

superposed on well-defined slow undulations of an average period of 0.65 second in the (EW), and 0.64 second in the (NS). One of the largest vibrations of the latter kind was $2a=1.0$ mm., $T=0.74$ second, direction N 30° E. In the (EW), there were also present vibrations whose average period was 1.3 seconds.

27. Eqke. No. 19. The 4th December, 1897; 9.19.21 a. m. Intensity, *weak*. The maximum H.M. was about 1.6 mm., the V.M. being also present. As the rotation of the record receiving drum was unfortunately not good, further measurement could not be made.

28. Eqke. No. 20. The 8th December, 1897; 5.20.48 p. m. Intensity, *weak*. Two shocks, (a) and (b), of nearly the same range of motion happened one after the other, the time interval between their occurrences being 43 seconds. The origin of disturbance was, like that of Eqke. No. 4 and its after-shocks, situated inland at about 100 km. W of Miyako. (See fig. 4). The total duration of the two shocks was 100 seconds.

(a) First shock. The *preliminary tremor*, whose duration was 11 seconds, and whose amplitude was greater in the (EW) than in the (NS), consisted of ripples of an average period of 0.089 second in the (EW), 0.088 second in the (NS), and 0.08 second in the (V); these movements being superposed on slow undulations of an average period of 1.7 seconds in the (EW), and 1.0 second in the (NS).

The *principal portion*, whose duration was about 12 seconds, consisted of ripples of the following elements :

	(EW)	(NS)	(V)
Maximum $2a$	0.74 mm.	0.9 mm.	0.1 mm.
Average period	0.10 second	0.10 second	0.10 second.

The average period of slow undulations was 1.6 seconds in the (EW), 1.8 seconds in the (NS), and 0.8 second in the (V), one of the maximum movements of this kind, whose period was 1.4 seconds, being :

0.8 mm. towards E, 0.6 mm. towards N, 0.7 mm. upwards.

Resultant $2a=1.2$ mm., direction . E 40° N, the angle of emergence= 36° .

In the *end portion*, the average period of the ripples was 0.085 second in the (EW), 0.08 second in the (NS), and 0.09 second in the (V) ; these being superposed on slow undulations of an average period of 1.7 seconds in the (EW), 0.9 second in the (NS), and 0.4 second in the (V).

(b) Second shock. The *principal portion*, whose duration was 7 seconds, consisted of ripples of the following elements :—

	(EW)	(NS)	(V)
Maximum $2a$:	0.5 mm.	0.6 mm.	0.1 mm.
Average period:	0.088 second	0.082 second	(obscure).

The ripples were superposed on slow undulations, whose average period was 1.6 seconds in the (EW), and whose maximum H.M.=1 mm., V.M.=0.2 mm.

In the *end portion*, the average periods were as follows :—

	(EW)	(NS)	(V)
Ripples:	0.074 second	0.077 second	0.079 second.
Slow undulations:	1.5 „	0.9 „	0.9 „

29. Eqke. No. 21. The 23rd December, 1897; 0.29.16 p. m. Intensity, *weak*. The origin was situated at about 70 km. NE of Miyako. The duration was about 35 seconds.

The *preliminary tremor*, whose duration was 3.6 seconds, consisted of very fine ripples of an average period of 0.05 second.

The *principal portion*, whose duration was 3.6 seconds, consisted of movements of the maximum $2a$ of 1.0 mm. in the (EW), and 1.2 mm. in the (NS), the amplitude of motion being nearly equal in the two horizontal components.

In the *end portion*, the motion consisted of ripples superposed on slight slow undulations.

30. Eqke. No. 22. The 26th December, 1897; 3 p.m. Intensity, *slight*. The date is possibly erroneous, there being in the Central Meteorological Observatory no report relating to this earthquake, which was evidently a rather great shock at a distance.

The duration was about 150 seconds.

The *preliminary tremor*, whose duration was 26 seconds, began very gradually and consisted of small slow undulations perfectly free from superposed ripples.

The *principal portion* consisted of slow undulations of an average period of 2.2 seconds, the motion being almost entirely in the (EW). The maximum motion was $2a=0.6$ mm., $T=2.3$ seconds.

The average period of the ripples superposed on the slow undulations in the principal portion was 0.11 second, the maximum $2a$ being 0.2 mm.

31. Eqke. No. 23. The 31st December, 1897; 11.50.28 p.m. Intensity, *slight*. The origin was situated to the ESE of Miyako. The duration was 70 seconds.

The motion, which consisted entirely of slow undulations free from superposed ripples, was about twice as great in the (EW) as in the (NS), V.M. being almost zero.

The *preliminary tremor* was not recorded, having probably been lost on account of its feeble intensity. The maximum motion, which occurred at the commencement, was $2a=1.1$ mm., direction N 60° E.

32. Eqke. No. 24. The 23rd April, 1898; 8.34.13 a.m. Intensity, *strong*. The origin of this extensive earthquake was situated probably at about 200 km. ESE of Miyako.

The duration of the H.M. was about 120 seconds. The V.M. was recorded till 20 seconds from the commencement, when the motion became very large and the pointer went off the record-receiver.

The *preliminary tremor*, whose duration was about 13 seconds, and whose range of motion was greatest in the (NS), consisted of ripples of the following elements:—

	(EW)	(NS)	(V)
Maximum $2a$:	1.2 mm.	1.5 mm.	0.3 mm.
Average period:	0.084 second	0.080 second	0.087 second.

The ripples were, as is usually the case with strong shocks, superposed on slow undulations.

The *principal portion*, whose duration was 19 seconds, was unfortunately vitiated by the proper oscillations of the seismograph pendulums. The average period of the ripples has, however, been measured and found to be 0.11 second in each horizontal component, the elements of the largest ripples being

(First vibration): $2a=6.4$ mm., $T=0.15$ second, direction NE.

(Second vibration): $2a=5.4$ mm., $T=0.18$ second, direction N 30° E.

In the *end portion*, the average period of the ripples was 0.06 second in the (EW); these being superposed on slow

undulations, whose average period was 0.93 second in the (EW), and 0.87 second in the (NS), and whose maximum motion was $2a=3.0$ mm., $T=1.2$ seconds.

33. Eqke. No. 25. The 19th May, 1898; 9.50.40 a.m. Intensity, *very slight*. This was a small local shock, whose origin was at about 43 km. S of Miyako.

The duration was only 10 seconds, the motion consisting entirely of small ripples of an average period of 0.069 second.

34. Eqke. No. 26. The 31st May 1898; 1.3.22 a.m. Intensity, *slight*. The origin was at about 80 km. ESE of Miyako.

The duration of the H.M. was 77 seconds, and that of the V.M. 43 seconds. The motion consisted of small ripples superposed on slight slow undulations, there being no prominent maximum movements.

The *preliminary tremor*, whose duration was 7.7 seconds, consisted of very fine ripples.

The *principal portion* consisted of ripples, whose maximum $2a$ was 0.1 mm. in each component, and whose average period was 0.085 seconds in the (EW), 0.085 second in the (NS), and 0.07 second in the (V); the period of the slow undulations, whose amplitude was very small, being 1.5 seconds in the (EW).

35. Eqke. No. 27. The 3rd June, 1898; 3.22.10 p.m. Intensity, *slight*. This was a small shock, whose origin was at about 52 km. SE of Miyako. The duration was 25 seconds.

The motion was rather greater in the (EW) than in the (NS), traces of the V.M. being also present.

The duration of the *preliminary tremor* was very short, and the maximum motion of 0.4 mm. occurred immediately after

the commencement, the average period being 0.089 second in the (EW), 0.081 second in the (NS), and 0.076 second in the (V).

Summary of Results.

The results are collected in the Table at the end of this paper, to which the following remarks may be prefixed.

36. *The area of earthquake disturbance.*

Of the earthquakes whose exact dates are known, No. 4 and its fore-and after-shocks, namely, Nos. 3, 5, 6, 8, and 19, originated in the mountain regions forming the boundary between the provinces of Rikuchu and Ugo, while the remaining 19 earthquakes all originated under the Pacific Ocean at variable distances from the coast. The isoseismal lines and the areas of disturbance of these earthquakes, the typical ones of which are illustrated in figs. 4, 5, 6, 7 and 8, were generally not circular, but more or less elliptical, with the longer axes parallel to the coast, that is to say, in a direction of N slightly E to S slightly W. In the last column of the Table, therefore, both the greatest and the least radii of propagation are given for each earthquake, the exceptions being Nos. 22, 26, 4, 5, 6 and 10, whose areas of disturbance were nearly circular. The smallest and the greatest among the 25 earthquakes here considered, were respectively No. 24 and No. 9, the radii of propagation of the former being 50 and 65 km. and those of the latter 430 and 700 km.

In those cases in which the earthquakes originated under the Pacific Ocean, the shocks were generally propagated only to an insignificant amount to the western coast of Japan. This is probably due to the seismic waves having been stopped by the heavy mountain masses running through the Main Island.

Propagation along the coast is, however, evidently much favoured by the geological formations, which generally run parallel to the coast. On the other hand, it is also very probable that the epifoci of most of the earthquakes under consideration were not points, but were linear and parallel to the axis of the Island. Thus, the forms of the isoseismal lines in figs. 4 and 5, suggest very naturally that the earthquakes, Nos. 20 and 8 were probably caused by long fissures or faults in the direction of nearly NEN—SWS.

37. *The position of the earthquake origin.*

Of the 25 earthquakes above considered, six originated at distances of 100 to 130 km. to the W or WSW of Miyako, while the remaining nineteen originated under the sea at distances between 40 and 210 km. to the ENE, E, or ESE of the same station. The positions of the nineteen suboceanic origins are included within a circle of about 2° radius, the centre being in long. 143° E, lat. 39° N. This point, which is at about 1° or 110 km. to the E of Miyako, is thus to be regarded as the most active centre of earthquakes disturbing the eastern part of Northern Japan.

As the majority of earthquakes disturbing Miyako, or more generally the eastern coast of Northern Japan, originate under the Pacific, it is to be expected that the shocks will sometimes, like No. 1 and No. 12, be accompanied by sea-waves. It may be that the disturbance of the sea occurs more or less whenever a sufficiently strong shock takes place, either at the sea-bottom itself or at a very small depth below it, so as to give commotion to the water. Of course, the same phenomena may be produced, when a comparatively sudden elevation or depression of the sea-bottom takes place.

38. *The duration of an earthquake.*

It is impossible to measure exactly the total duration of an earthquake, which is of course much longer when instrumentally recorded than when simply felt without such an aid. Again, the duration recorded by an instrument depends on its sensibility. Thus, for instance, the duration of motion in Eqke. No. 23 was, as given in the Table, only 120 seconds; but the duration of the same earthquake in Tokyo, recorded by Omori's Horizontal Pendulum, was 2 hours. The fact is that the ordinary seismographs of the Ewing and Milne and Gray types so widely used in Japan, are capable of registering only the quicker vibrations of an earthquake but insensitive to waves of long period, the latter being very easily obscured by the friction of the instruments.

The total earthquake durations given in this paper, which varied between 8.5 and 200 seconds (see the 3rd column of the Table), are to be regarded as the durations of the sharper vibrations in different earthquakes, namely of those waves causing the greatest effects on our senses.

Speaking generally, the duration of an earthquake will depend both on its magnitude and on the distance of the observing station from the origin. As a rough approximation, let us assume

$$D = \frac{A}{k \pi d},$$

in which $\pi=3.1416$; k is a constant; D , the duration in seconds of an earthquake (less the duration of the preliminary tremor) at a given station; d the distance in kilometres between the origin and the observing station; and A the area of disturbance, in which the intensity of motion is sufficiently strong

to be generally felt without any instrumental aid. The values of the constant k , given in the 6th column of the Table vary within rather wide limits, namely, 4 and 28, but it would be impossible to expect any very perfect agreement between several cases, as, besides the difficulty of accurately measuring the duration, D , the value of the area of disturbance, A , is very apt to be subjected to accidental modifications, the origins being, in the present cases, mostly submarine. The average value of k is 13.6, so that the above equation becomes, for Miyako,

$$D=0.024 \times \frac{A}{d}.$$

Further discussions of this question shall be made in the report on the Tokyo seismometrical observations to be soon published.

39. *The duration of the vertical motion.*

The relation of the duration of the vertical motion, measured in 14 cases, to that of the horizontal, was as follows.

In 5 cases, the durations of the two components were equal to each other; in 1 case, the V.M. lasted longer than the H.M. in the ratio of 1.2:1; and in the remaining 8 cases, the duration of the V.M. was shorter than that of the H.M., the ratios being respectively 0.6:1, 0.8:1, 0.8:1, 0.4:1, 0.5:1, 0.7:1, 0.6:1 and 0.6:1. Taking the average of these 14 cases, the durations of the vertical and the horizontal components were in the ratio of 0.8:1.

40. The duration of the *principal portion* of an earthquake, which is much shorter than that of the whole of it, varied in the present cases, as given in the 5th column of the Table, between 0.7 and 26.0 seconds. The principal portion is generally

well-defined for comparatively near shocks, but often very indefinite for distant ones.

41. The duration of the preliminary tremor, which has been measured in 24 cases, varied between 0 and 26 seconds. As already discussed by one of the present authors,¹ the duration of the preliminary tremor of an earthquake, y (expressed in seconds), at a given station seems to be related to the distance of the latter from the origin, x (expressed in kilometres), by the following linear equation—

$$7.51 \ y = x - 24.9 \text{ km.} \quad (2)$$

x being assumed to be sufficiently great, say, greater than 100 kilometres, or y greater than 10 seconds. The approximate distances of the epicentres from Miyako have been calculated by means of equation (2) in 11 cases, in which the duration of the preliminary tremor was greater than 10 seconds. These results are given in the 17th column of the Table, while the distances judged from the earthquake maps are given in the 16th column.

It will be observed that the two sets of values given in columns 16 and 17 agree on the whole pretty well with each other. Thus, the mean value of the distances under consideration deduced from eight cases, namely, Nos. 2, 3, 12, 13, 14, 17, 19 and 23, is according to equation (2), 160 km., and according to the method of seismic maps, 180 km.

42. *The period of vibration.* In the Table are given for different earthquakes the complete periods of maximum movements, as well as the average complete periods of vibrations in

1. *F. Omori.* Note on the preliminary tremor of earthquake motion.

the *preliminary tremor*, the *principal portion*, and the *end portion*, with respect to both the ripples and the slow undulations.

The period of the maximum H.M. varied, for slow undulations, between 0.53 and 1.7 seconds; and, for ripples, between 0.12 and 0.15 second. The corresponding period in the vertical motion varied, for slow undulations, between 0.53 and 1.7 seconds, the vertical and the horizontal components having, in most cases, the same period.

With regard to ripples, the period, which was identical in all the three components of an earthquake, became generally a little longer in the *principal portion* than in the *preliminary tremor*. Thus, for the latter epoch, the mean value of the average periods which varied between 0.04 and 0.087 second, was 0.08 second; while that of the average periods for the former epoch, which varied between 0.055 and 0.12 second, was 0.10 second. For the *end portion*, the mean value of the average periods of ripples, which varied between 0.06 and 0.10 second, was 0.08 second, namely the same as in the case of the *preliminary tremor*. The average period of ripples in the *principal portion*, which are characterized by their having larger amplitude, is thus seen to be longer than that in the two other portions of the earthquake motion, the difference amounting to 0.02 second.

For the *principal portion*, the mean value of the average periods of horizontal slow undulations, which varied between 0.56 and 1.7 seconds, was 1.3 seconds in the (EW) and 1.0 second in the (NS); while the mean of the corresponding quantities for the *end portion*, which varied between 0.9 and 1.7 seconds, was 1.3 seconds in (EW), and 0.94 second in the (NS). Thus, for the horizontal slow undulations, the average

period seems to remain approximately constant in the principal and the end portions. These undulations existed more or less also in the *preliminary tremor*, the mean of the average period being 1.1 seconds in the (EW) and 1.0 second in the (NS).

For the V.M., the mean of the average periods of slow undulations was about 0.8 second.

It is remarkable that the average period of ripples remained roughly constant in the different earthquakes here considered, never varying much from 0.1 second. It is possible that these ripples were preceded by, or superposed upon, very minute vibrations of still shorter periods.

43. *The range of motion.* The maximum ranges of motion in different earthquakes are given in the 9th column of the Table. The greatest ripple of 7.4 mm. occurred in Eqke. No. 11, the next greatest of about 5 and 6.4 mm. occurring respectively in Eqke. No. 4 and Eqke. No. 23. The greatest slow undulations, which probably occurred in these two earthquakes, were unfortunately confused by the proper oscillations of the pendulums serving as the "steady masses" of the seismograph. As an example, in which this element of motion was satisfactorily measured, Eqke. No. 3 may be mentioned, the maximum range of motion in question being 9.1 mm.

The range of V.M. was invariably smaller than that of the corresponding H.M., the maximum motions of the two components being, for ripples, in the average ratio of 0.20:1; and for slow undulations, in the average ratio of 0.21:1.

44. *The direction of motion.* The motion in the principal portion was, with the exception of one case or two, always greater in the (EW) than in the (NS). For the preliminary tremor, however, no such peculiarity was found, the ratio of the ranges

of motion in the two horizontal components during this epoch having generally no relation to the corresponding ratio for the principal portion.

The directions of the maximum movements in different earthquakes are given in the 10th column of the Table, from which it will be observed that these were, with the exceptions of Eqkes. No. 5 and No. 16, nearly EW, ESE—WNW or ENE—WSW. (See fig. 9). It will also be seen that the majority of the suboceanic earthquake origins were situated towards the E, ESE and ENE of Miyako, so that we may, in a general way, say that the directions of the maximum earthquake movements were nearly coincident with the directions of the lines joining the observing station with the epicentres. The fact that the origins under consideration were chiefly in the directions of SE or ESE from Miyako, while the majority of the directions of the maximum movements were included between the directions EW and NE—SW, seems to indicate some peculiarity inherent in the region about the observing place, causing the direction of motion in different earthquakes to approach to a certain prevailing direction.

In the cases of nine earthquakes, Nos. 1, 2, 3, 8, 10, 14, 16, 19 and 22, the directions of the maximum movements did exactly, or roughly, coincide with the respective directions of the origins from Miyako; and especially, in three earthquakes, Nos. 8, 11 and 20, the angles of emergence have been measured respectively to be $7^{\circ}.2$, 9° and 36° . Of these three last earthquakes, two, namely, Nos. 8 and 20, were the after-shocks of the Eqke. No. 4; while the remaining one, No. 11, had its origin under the Ocean, towards NE of Miyako. The value of 36° for Eqke. No. 20 was evidently too great, the error being probably

due to its having been obtained, not from the principal portion, but from the preliminary tremor of the earthquake. Omitting this case, we obtain for the focal-depths of the two earthquakes Nos. 8 and 11, respectively the values of 15 and 9 km.

December, 1898.

Seismological Institute,
Tokyo Imperial University.



Table showing the results of seismographical observations at Miyako.

No.	Date of occurrence.	Total duration, in seconds.	Duration of the preliminary tremor, in seconds.	Duration of the principal portion, in seconds.	Value of k (See § 38).	Preliminary tremor.		Principal portion.						End portion.		Distance of epic. origin from Miyako, estimated from seismic maps, in km.	Distance of epic. origin from Miyako, according to eqs. (2), (4), (5), in km.	Direction of epic. origin from Miyako.	Greatest and least radii of the area of disturbance, in km.
						Average period of ripples, in seconds.	Average period of slow undulations, in seconds.	Maximum motion, in mm.	Direction of the maximum motion.	Complete period of the max. motion, in seconds.	Average period of ripples, in seconds.	Average period of slow undulations, in seconds.	Average period of ripples, in seconds.	Average period of slow undulations, in seconds.					
1	15th June 1896 7:52.30 p. m.							4.0	E-W							170.		ESE	600 x 300
2	17th June 1896 9:46.23 p. m.	(H) 56. (V) 56.	13.		20.	(EW) 0.9 (V) 0.6		4.1	W 25° S Angle of emerg. = 4°	1.7		(H) 0.8; 1.4 (V) 1.3		(EW) 1.2 (NS) 1.0		170.	123.	ENE	520 x 310
3	31st Aug. 1896 4:42.15 p. m.	73.	16.	4.	14.	0.07 (H) 1.4 (V) 1.3		9.0	S 70° W-N 70° E	(H) 0.94 (V) 0.9		(H) 1.0 (V) 0.9	(EW) 0.09 (V) 0.06			160.	100.	S 80° W	330 x 70
4	" 5:09.55 p. m.	160.	5.2	26.	26.		0.8	(Motion not well recorded) ripple (EW) 3.4 (NS) 3.4				(H) 0.087 (V) 0.064				100.		S 80° W	500 x 500
5	" 7:20.52 p. m.	50.	5.7		13.	(EW) 0.05 (NS) 0.04	(H) 0.87	(H) 2.2 (V) 0.3	N 20° W	(H) 0.56 (V) 0.95	0.055	(EW) 0.68 (NS) 0.58 (V) 0.32				110.		W slightly S	250 x 250
6	1st Sept. 1896 2:55.15 p. m.	(H) 58. (V) 56.			18.			(EW) 0.4 (NS) 0.1 (V) 0.14								100.		"	250 x 250
7	5th Sept. 1896 11:09.25 p. m.	35.			20.			(EW) 3.6 (NS) 3.0 (V) 0.4								130.		ENE	300 x 300
8	7th Feb. 1897 4:35.30 p. m.							28. (EW) 0.4 (NS) 0.9 (V) 0.1	W 25° S Angle of emerg. = 7.2	Aloud 1.2						130.		S 60° W	200 x 300
8 ^a																			
9	29th Feb. 1897 5:40.00 a. m.															220.		SE	430 x 700
10	27th March 1897 7:46.43 p. m.	(H) 86. (V) 47.	4.2	24.	16.	0.078		(H) 0.39 (V) 0.08			(H) 0.697 (V) 0.091		(EW) 0.076 (V) 1.1	1.5		70.		ENE	240 x 350
11	29th April 1897 5:54.15 a. m.	(H) 42. (V) 33.	2.6	0.7	8.	(H) 0.075 (V) 0.07		1.6	NE-SW, Angle of emerg. = 9°	0.12	0.12	(H) 0.084 (V) 0.084				60.		NE	140 x 140
12	18th June 1897 1:18.05 p. m.	(H) 50. (V) —	8.5	9.	12.	(H) 0.08 (V) 0.064		7.4	E 30° N-W 30° S		(H) 0.11					90.		SE	170 x 260
13	5th Aug. 1897 9:10.47 a. m.	(H) 150. (V) 150.	22.		7.	(EW) 0.07 (NS) 0.06	(NS) 0.8	(EW) 1.8 (NS) 0.9 (V) 0.57		(EW) 0.67 (NS) 0.60 (V) 0.67	(EW) 0.087 (NS) 0.08 (V) 0.7	(EW) 0.82 (V) 0.7				220.	190.	SE	280 x 650
14	7th Aug. 1897 9:09.07 p. m.	(H) 150. (V) 60.	21.		4.	(EW) 0.08		(H) 0.9 (V) 0.12	NE	(H) 1.0 (V) 0.8						170.	108.	SE	260 x 350
15	16th Aug. 1897 4:53.03 p. m.	(H) 140 (V) 70.	16		9.	(H) 0.083 (V) —	(NS) 1.0	(Ripple) 0.64 (Slow undulation) 2.8 (V) 0.4		0.12 (H) 1.6 (V) 0.7						170.	145.	ESE	350 x 920
15 ^a		23.	7.8			0.076		0.2			0.084								
16	25th Aug. 1897 9:32.56	(H) 100. (V) 70.	11.	9.3		(H) 0.087 (V) 0.086		(H) 2.1 (V) 0.3		(H) 0.14	(H) 0.11 (V) —		(H) 0.10 (V) —	(EW) 1.7 (NS) 1.9 (V) 0.5			110.		
16 ^a		23.	0								0.083 (V) 0.08								
17	27th Aug. 1897 1:06.31 a. m.	(H) 76 (V) 30.	21.		15.			(H) 1.0 (V) 0.1	W 30° N	(H) 1.2		(EW) 1.6 (NS) 0.8				160.	183.	SE	250 x 920
17 ^a		26.	0								0.09								
18	2nd Oct. 1897 9:42.03 p. m.	(H) 110	12.5	13.6	16.	(H) 0.07 (V) —	(H) 0.9 (V) —	(Ripple) (H) 1.5 (NS) 0.9 (V) 0.1 (Slow undul.) (H) 2.3 (V) 1.4	W 15° S W 35° S	(H) 0.12 (H) 1.0	(H) 0.69 (V) —	(H) 1.2 (V) 1.0	(H) 0.06 (V) —	(H) 0.65; 1.3 (V) —		150.	120.	ESE	380 x 540
19	4th Dec. 1897 9:19.21 a. m.							(H) 1.6 (V) —								160.		SE	280 x 500
20	8th Dec. 1897 5:20.48 p. m.	100. { 1st epic. 2nd epic.	11.	12.	24.			(Ripple) (EW) 0.74 (NS) 0.9 (V) 0.1 (Slow undul.) (H) 1.2 (H) 1.0 (V) 0.2	E 40° N, Angle of emerg. = 76°	1.4	(H) 0.10 (V) 0.10	(H) 1.7 (V) 0.8	(H) 0.083 (V) 0.09	(EW) 1.7 (NS) 0.9 (V) 0.4		160.	100.	W	87 x 270
21	23rd Dec. 1897 9:29.16 p. m.	35.	3.6	3.6		(H) 0.05		(EW) 1.0 (NS) 1.2 (V) —								70.		NE	210 x 280
22		150.	26.					0.6	E-W	2.27	0.11	2.27				220.			
23	31st Dec. 1897 11:50.28 p. m.	70.	0					1.1	E 30° N			(EW) 1.5 (NS) —						ESE	100 x 100
24	2nd April 1898 8:34.13 a. m.	(H) 120 (V) —	13.	1.9	14.	0.084		(One of ripples) (H) 6.5		0.15	(EW) 0.11 (V) —		(EW) 0.06 (H) 0.9			200.	120.	ESE	380 x 650
25	19th May 1898 9:50.40 a. m.	10.	0		8.								(EW) 0.069			43.		S	30 x 65
26	31st May 1898 1:03.22 a. m.	(H) 77. (V) 43.	7.7		7.						(H) 0.085 (V) 0.07	(EW) 1.5				95.		SE	250 x 170
27	3rd June 1898 3:22.10 p. m.	25. very short.			5.						(H) 0.085 (V) 0.076					62.		SE	80 x 80

(H) denotes Horizontal Component
(V) denotes Vertical Component(EW) denotes EW-component
(NS) denotes NS-component



Fig. 1. The Earthquake of June 17th, 1896; 0. 46. 25 p. m.

(Observed at Miyako).

Multiplication of horizontal motion 5 times, that of vertical motion 10 times.

The beginning of motion is marked a.

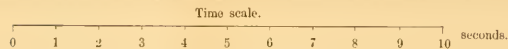
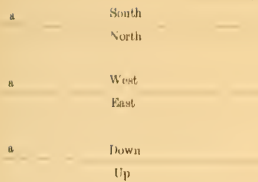


Fig. 2. The Earthquake of August 31st, 1896; 4. 42. p. m.

(Observed at Miyako).

Multiplication of horizontal motion 5 times, that of vertical motion 10 times.

The beginning of motion is marked a.

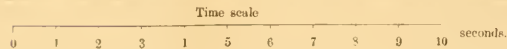
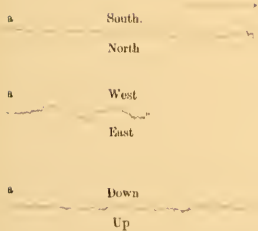


Fig. 3. The Earthquake of April 30th, 1897; 5. 51. 15 a. m.

(Observed at Miyako).

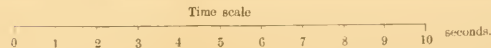
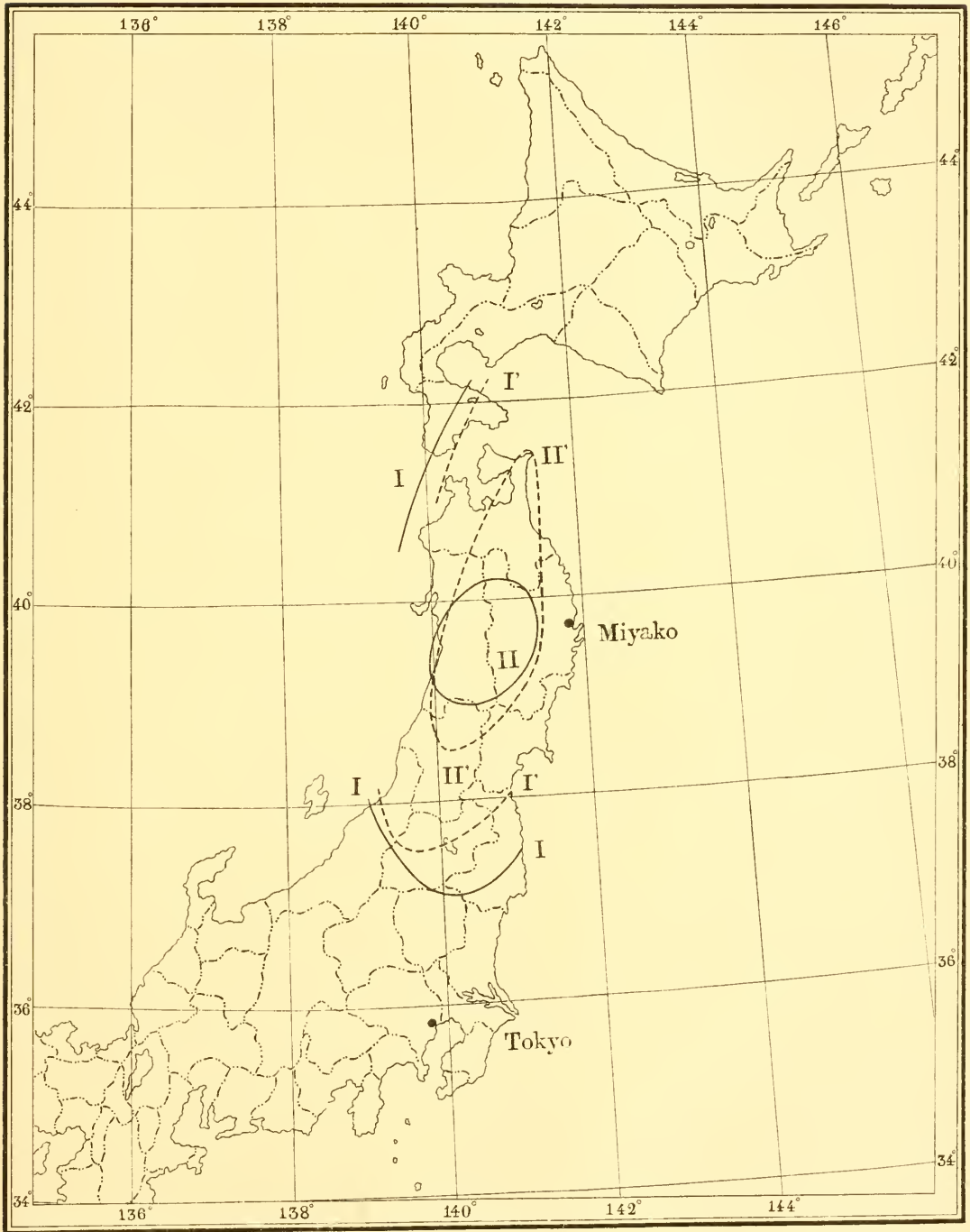


Fig. 4. The Earthquakes of Aug. 31st, 1896, and of Dec. 8th, 1897.

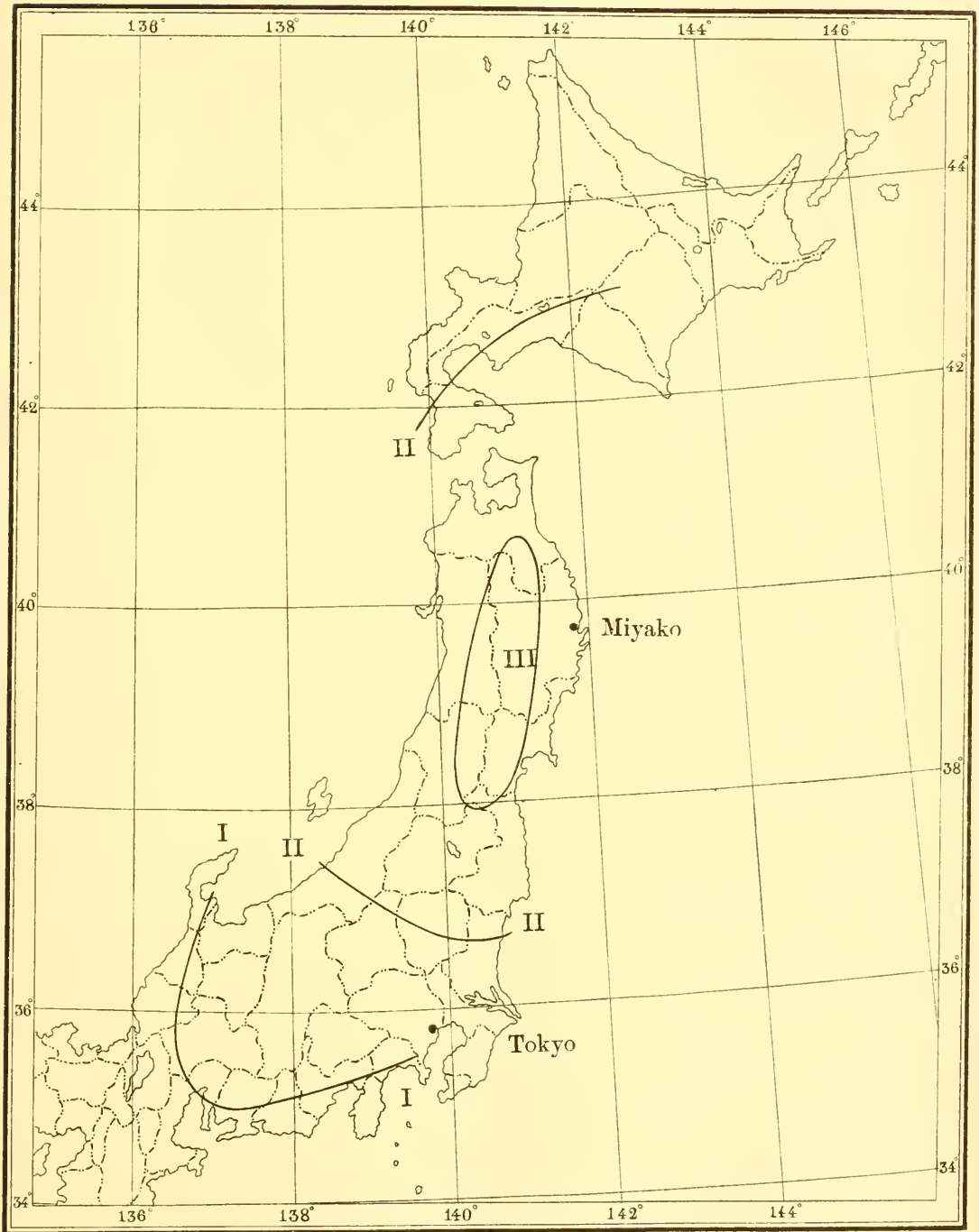


----- Boundary of provinces.

Full curves, I and II, refer to the eqke of Aug. 31st, 1896, and dotted curves, I' and II,' to that of Dec. 8th, 1897.

I, I' Boundary of the area of slight motion.
 II, II,' " " " " " strong "

Fig 5. The Earthquake of February 7th, 1897.



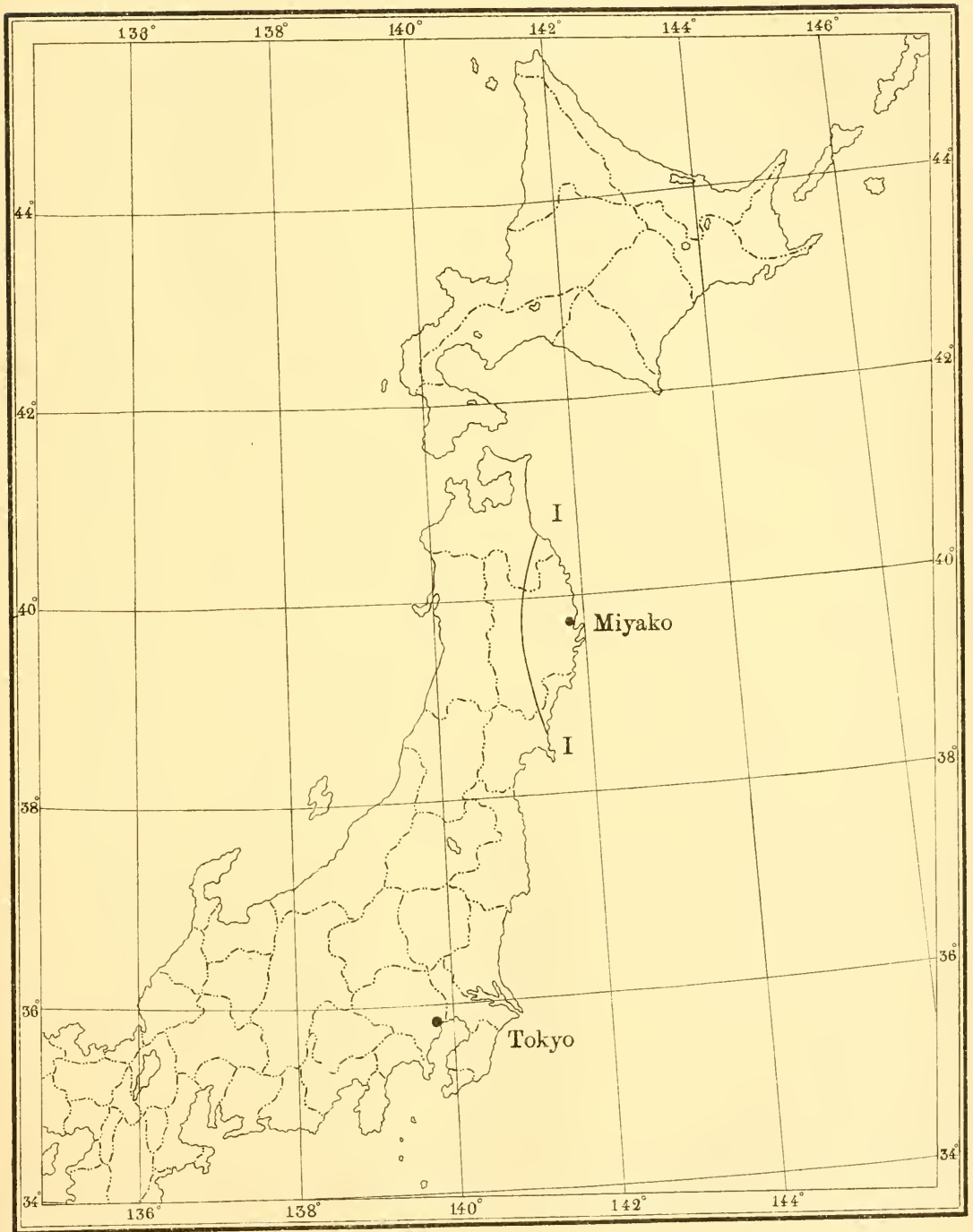
--- Boundary of provinces.

I. Boundary of the area of slightest motion.

II, " " " " slight "

III, " " " " strong "

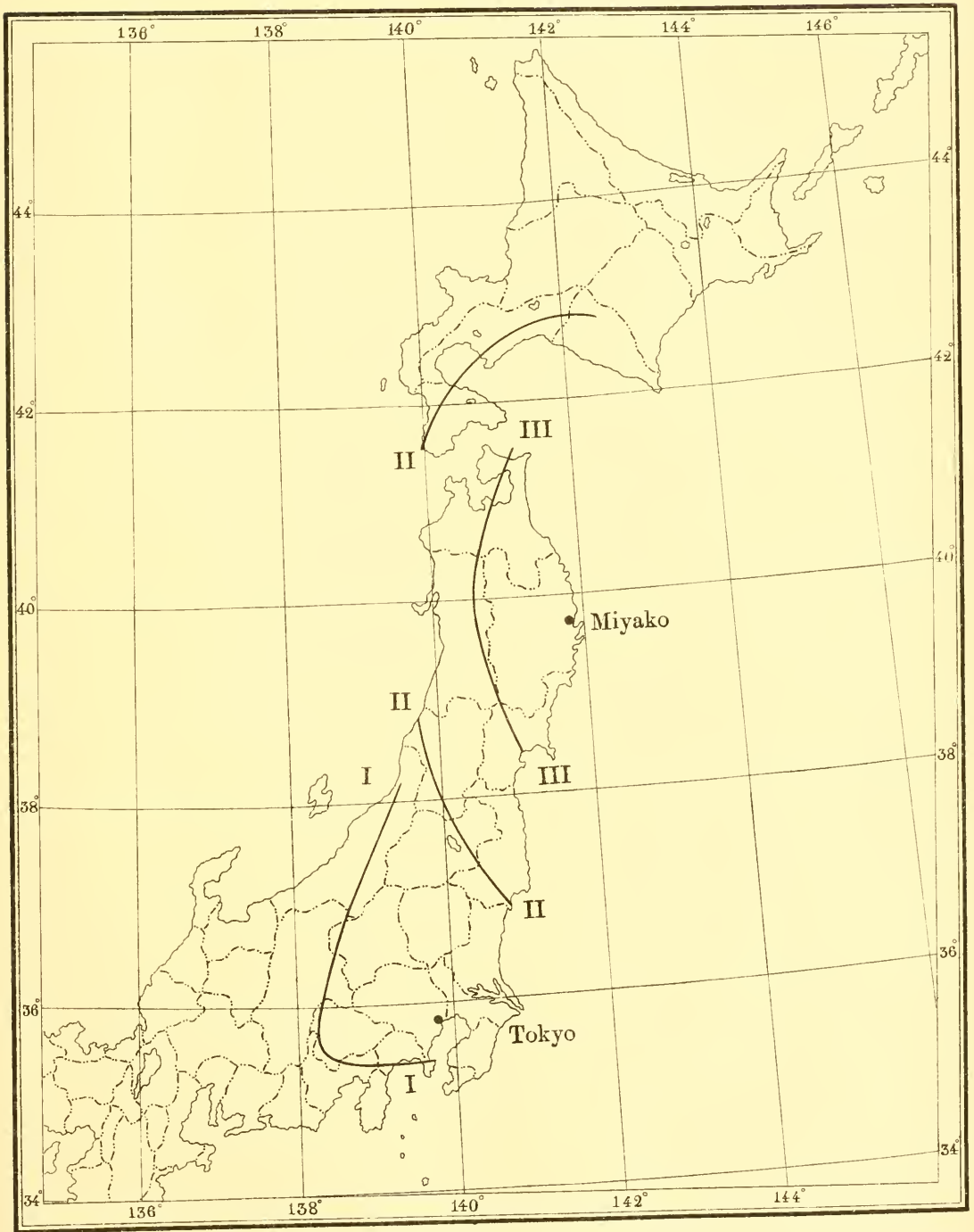
Fig. 6. The Earthquake of April 30th, 1897.



----- Boundary of provinces.

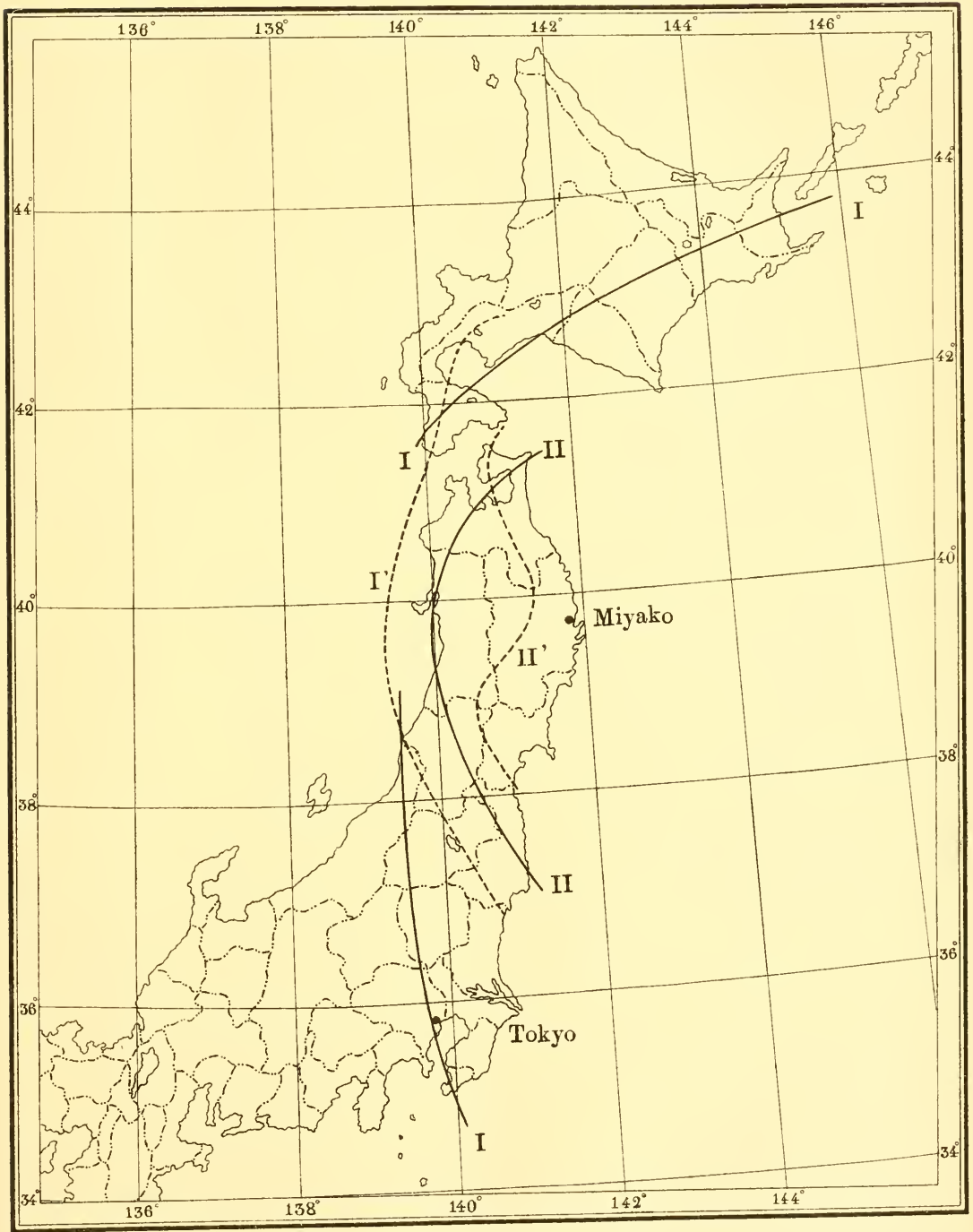
I, Boundary of the area of slight motion.

Fig. 7. The Earthquake of March 27th, 1897.



----- Boundary of provinces.
 I, Boundary of the area of slightest motion.
 II, " " " " " slight "
 III, " " " " " weak "

Fig. 8. The Earthquakes of June 15th and 17th, 1896.

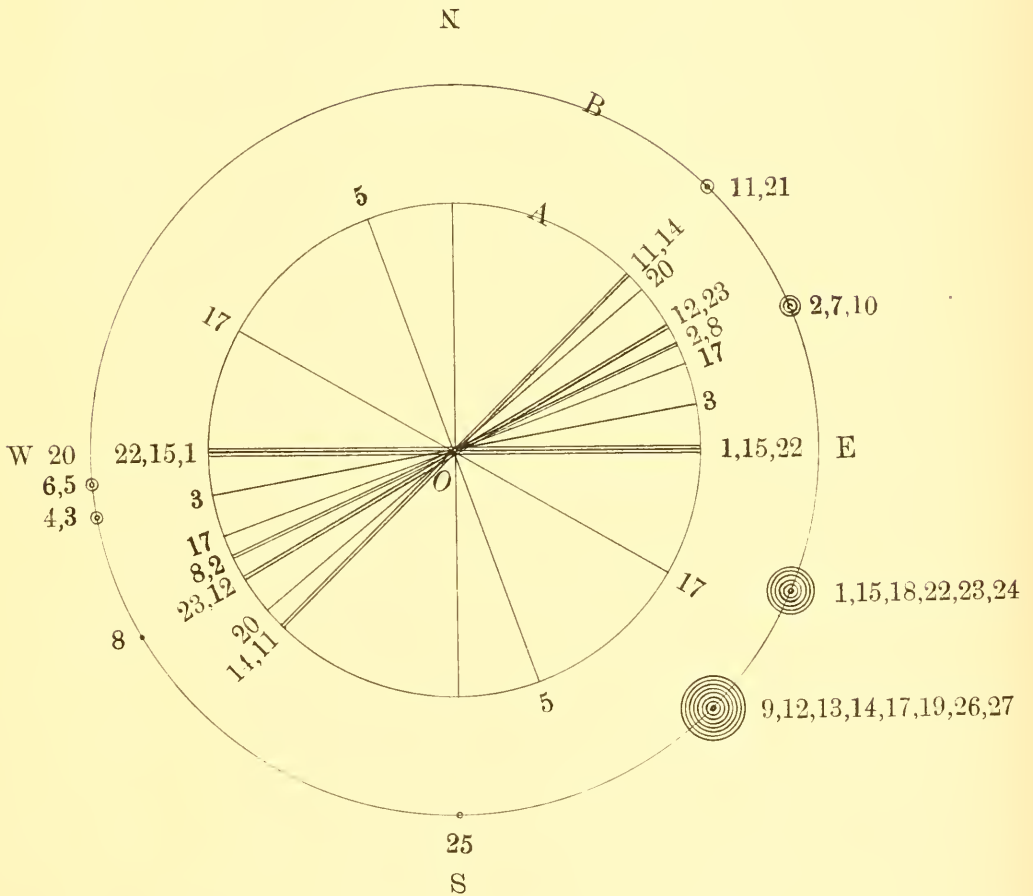


----- Boundary of provinces.

Full curves, I and II, refer to the eqke of June 15th, and dotted curves, I' and II', to that of June 17th.

I', I' Boundary of the area of slight motion.
 II, II, " " " " " " weak " "

Fig. 9.—Diagram showing the directions of maximum movements in the different earthquakes at Miyako.



Note.—The diameters of the inner circle, A, indicate the directions at Miyako of maximum movements in the different earthquakes; and the points or small circles on the circumference of the outer circle, B, indicate the azimuthal positions of the earthquake origins, the central point, O, being supposed to represent Miyako. The numbers are the same with those of earthquakes as given in the List, § 2.

Ethyl ammoniumsulphite.

By

Edward Divers and Masataka Ogawa,

Imperial University, Tōkyō.

In attempts to obtain ammonium amidosulphite, which proved successful only when made in another direction, we have found that, in absence of water and at a low temperature, ammonia and alcohol unite with sulphur dioxide and form a new salt of the composition of ammonium ethylsulphonate and yet quite distinct from it. Evidently, ammonia and alcohol react with sulphur dioxide as though they were ethylammonium hydroxide, for ammonia in the cold has no action upon ethylsulphite or upon ethyl ethylsulphonate and, when heated with the former produces ethylamine and ammonium sulphite (Carius, *Ann.*, 1859, **110**, 221), and with the latter ethylammonium ethylsulphonate (Carius, *J. pr. Ch.*, 1870 [2] **2**, 262).

Warlitz' potassium ethyl sulphite, never but doubtfully distinct from a sulphonate, has now been shown to be none other than potassium ethylsulphonate (Rosenheim and Liebknecht, *Ber.*, 1898, **31**, 405). From the experiments of Carius and from those of the chemists just named, it is also certain that ethyl sulphite does not react directly to form a salt intermediate to itself and potassium sulphite, and is thus distinguished from a sulphonate, as Carius pointed out (see also the action of ammonia, just referred to above).

But, within the last few years, a new class of alkyl metallo-sulphites has come to be known and in this class the new ethyl ammoniumsulphite must be placed. The first member to be discovered was phenyl sodiumsulphite (Schall, *Ber.*, 1892, **25**, 1875; *J. pr. Ch.*, 1893, [2] **48**, 241), formed from sodium phenoxide and sulphur dioxide; next, came methyl magnesium-sulphite, obtained by Szarvasy (*Ber.*, 1897, **30**, 1836) from magnesium methoxide and sulphur dioxide, and, lastly, methyl and ethyl sodiumsulphite and ethyl potassiumsulphite, prepared from sodium or potassium ethoxide or methoxide, as the case required, and sulphur dioxide (Rosenheim and Liebknecht, 1898, *loc. cit.*).

Schall has established that his salt is $\text{Na} \cdot \text{SO}_2 \cdot \text{OC}_6\text{H}_5$, and Rosenheim and Liebknecht have given good reasons for regarding their salts, and also Szarvasy's salt, as similarly constituted — $\text{Na} \cdot \text{SO}_2 \cdot \text{OC}_2\text{H}_5$; $\text{Mg}(\text{SO}_2 \cdot \text{OCH}_3)_2$, that is, as having a constitution complementary to that of sulphonates. Szarvasy, indeed, takes his sulphite to have a constitution analogous to that of the ethyl magnesium carbonate, which he has obtained in a similar way, but, in doing so, he ignores, what seems so well established, that sulphites behave as the analogues of formic acid and other carboxylic salts, rather than of carbonates, though producible in the same way as the latter salts.

Quite special precautions have to be taken to ensure the absence of water. Muspratt, passing "dried" sulphur dioxide and ammonia into ether, was surprised to get ammonium pyrosulphite: Carius found that "carefully dried" sulphur dioxide formed only sodium sulphite when led into sodium ethoxide dissolved in "*absolute*" alcohol (the italics are his), although,

as a fact, it does combine with the ethoxide. Both chemists had failed in their attempts to exclude water, and we, too, have failed to keep back all moisture. In 100 cc. of concentrated alcoholic ammonia, we had never much less than 80 mgm. water, but, fortunately, we could still eliminate this, as anhydrous ammonium sulphite, which is insoluble in alcohol.

The alcohol, at its final distillation from lime, was received direct into the reaction-flask, which was then closed by a dried cork provided with inlet and outlet tubes, the latter dipping into mercury as a seal. Ammonia, partially dried by passing it up a spiral tube immersed in a cooling mixture, was then sent through a series of tubes, packed with crushed and recently fused potassium hydroxide, into the alcohol in the reaction-flask, which was kept cool in a freezing-mixture. When ammonia began to freely escape through the mercury, no more of it was sent in, and a current of sulphur dioxide, well dried by sulphuric acid, passed in slowly until this gas in turn began to bubble freely through the mercury, when the current was stopped. While the sulphur dioxide was being passed into the flask, care was taken to keep the temperature of the ice-and-salt mixture, as nearly as practicable, down to -15° , and to agitate the flask. There was a double reason for keeping the temperature low, for, in the first place, a very concentrated solution of ammonia in the alcohol must be begun with, in order to get the greater part of the alcohol taken up afterwards in forming the new salt, and thus lead to the crystallisation of the latter by removal of the alcohol, in which it is quite soluble. The other purpose served by the low temperature was to prevent any of the sulphur dioxide from acting oxidisingly upon the ammonia, and thereby producing an orange-

coloured impurity (apparently nitrogen sulphide) and ammonium sulphite.

After passing the sulphur dioxide in for a short time, the turbid solution produced had to be allowed to clear and then be decanted, with as little exposure to air as possible, from a small deposit (0.5 grm. or less) of anhydrous ammonium sulphite, into another reaction-flask. This sulphite represented the small amount of moisture carried into the alcohol by the ammonia or otherwise. The introduction of sulphur dioxide being resumed, transparent four-sided prisms began to form when the ammonia was nearly saturated, and then so rapidly increased in quantity as to have dried up nearly all the solution by the time the ammonia was all gone. If at this point the operation was arrested and the flask brought to the common temperature and placed in a vacuum-desiccator, it was found to be impossible to get the crystals pure enough for analysis, because there was not only the liability of this exceedingly hygroscopic substance to condense a little moisture to contend with, but also its mother-liquor contained something in solution which remained as a viscid, non-volatilising residue which was probably pyrosulphite, $\text{Et Na S}_2\text{O}_5$. Instead, therefore, of stopping the entrance of more sulphur dioxide into the flask when all ammonia had been neutralised, the operation was continued for a much longer time until, as stated above, much sulphur dioxide passed uncondensed. By this time, the crystals had disappeared, being slowly dissolved up as the sulphur dioxide increased in quantity. Whether this was a case of mere solution in the sulphur dioxide, liquefied at so low a temperature, or was due to the formation of pyrosulphite, cannot with certainty be said.

In order to get back the salt in the solid state, the solution was poured, in portions suitable for analysis, into small flasks of ether, freshly distilled from sodium. The two liquids did not at first mix, but by gentle rotation the sulphite solution coated the flask and crystallised on its walls, while much sulphur dioxide escaped. On now pouring off the ether and washing the crystals with more ether, the salt dried rapidly in the desiccator and was then weighed in the same flask. The ether left no residue on evaporation.

The analysis of the salt was simple. Distillation with alkali gave the ammonia and alcohol, which were received in volumetric acid. After titrating for ammonia, the neutral distillate was again distilled, and the specific gravity and weight of the new distillate taken in order to determine the quantity of alcohol. The alkali sulphite in the distilling flask was heated in a pressure tube with hydrochloric acid and again rendered alkaline and distilled, in order to be certain that no amidosulphate had been formed, which was in fact the case. The sulphur dioxide was determined in a separate portion of the salt by oxidising, first, with bromine and alkali and, then, with potassium chlorate and hydrochloric acid, and precipitating sulphate by barium chloride. The quantities of salt serving for the analyses were about 2 grams each.

$C_2H_5(NH_4)SO_3$: alcohol ; 36.22 ; ammonia, 13.38 ; sulph. dióx., 50.39, per cent.
 Found : ,, 35.87 ; ,, 13.35 ; ,, 49.99, ,,

Ethyl ammoniumsulphite is crystalline and sublimes unchanged almost completely when heated in a dry tube and without blackening. It is decomposed violently by strong sulphuric acid and also without blackening. Acids at once set

free sulphur dioxide. It is insoluble in ether, soluble in alcohol without change, and recoverable from its solution by evaporation unchanged, provided every trace of water is kept away. It is also in part precipitated from its concentrated solution in alcohol, by saturating this with ammonia at a low temperature. It is exceedingly deliquescent and is immediately decomposed by water, in which it dissolves. Its alcoholic solution at once crusts over when exposed to the air, ammonium pyrosulphite being produced. The aqueous solution or deliquesced salt smells strongly of sulphur dioxide and gives the reactions only of a sulphite in its fresh state; but from the tendency of pyrosulphite to change into trithionate, it becomes a little yellow on standing and its silver precipitate slowly changes colour. Hydrochloric acid gives no precipitate of sulphur in its fresh solution, and the acid solution loses all its sulphur as sulphur dioxide, when quickly boiled.

Szarvasy found it necessary, in preparing methyl magnesiumsulphite, to saturate the alcoholic solution with sulphur dioxide, while, for the reason above given, we found it advantageous to saturate the alcohol with sulphur dioxide in preparing the ethyl ammoniumsulphite. Rosenheim and Liebknecht, on the other hand, state that the use of any excess of sulphur dioxide in making the alkyl alkalisulphites is most carefully to be avoided, since otherwise these salts decompose into "acid" alkalisulphites. This difference between closely allied salts would be remarkable and not easy to understand if its existence could be confirmed. In absence of water, pyrosulphites, rather than acid sulphites, alone can form. But, if the unknown ethyl sodiumpyrosulphite had been the salt formed, these chemists would, presumably, not have failed to indicate the

fact. Again, if sodium pyrosulphite and ethyl pyrosulphite had been the products, then the latter would also have been noticeable as a compound new to science. Szarvasy's and our own experience and the difficulty of interpreting Rosenheim and Liebknecht's results have caused us to prepare ethyl sodiumsulphite and test its behaviour with sulphur dioxide.

Sodium, bright and clean-cut under dried ether, was quickly transferred to a little dry alcohol in a small flask until the solution thickened and became inactive on more sodium. The solution was quickly decanted, in a cold, dry atmosphere, into another flask and cooled in a freezing mixture, which caused abundant crystallisation of sodium ethoxide. Sulphur dioxide was now passed in until it was in large excess in the liquefied state. Its effect was to cause the sodium ethoxide to gradually dissolve and give place to the micaceous crystals of Rosenheim and Liebknecht's salt, until the solution had almost all dried up. After this, it appeared to have no further action. The very sulphurous mother-liquor was drained off and the flask placed in a vacuum-desiccator to dry its contents. The dry salt was weighed in the preparation-flask and then aqueous solution of potassium hydroxide poured on to it. Oxidised, first by bromine and then by potassium chlorate and hydrochloric acid, it gave 24.67 per cent. sulphur, thus, confirming the observation that the salt did not seem to be affected by excess of sulphur dioxide, for the calculated quantity of sulphur in ethyl sodiumsulphite is 24.24 p. c. We conclude, therefore, that Rosenheim and Liebknecht failed to guard sufficiently against the entrance of moisture, and that their salts are not destroyed by dry sulphur dioxide. The sulphur dioxide mother-liquor poured off in our experiment

was left standing for some time in an open flask, and was only then placed in a desiccator. It left a small quantity of sodium pyrosulphite as a white powder. The salt is therefore a little soluble in alcoholic sulphur dioxide and then by absorbing water becomes alcohol and sodium pyrosulphite.



Ethyl ammonium selenite and Non-existence of Amidoselenites (selenosamates).

By

Edward Divers and Seihachi Hada,
Imperial University, Tōkyō.

Ethyl ammonium selenite.

In absence of water, selenion dioxide proves to be quite indifferent to ammonia in the cold or to its solution in ether. Although not very soluble in alcohol alone, it dissolves freely in alcoholic ammonia to become, in absence of water, a new salt, ethyl ammonium selenite, obtainable in the solid state, either by evaporating the alcohol or by precipitating the salt with dry ether. Hinsberg (*Ann.*, 1890, **260**, 40) has found that an alcoholic solution of selenion dioxide, free from all water, leaves on evaporation crystals of ethyl hydrogen selenite, which decompose slowly in dry air into alcohol and selenion dioxide again, or at once on contact with water into alcohol and selenious acid. He also obtained what appeared to be the aniline salt of this compound, in an impure state, by mixing and evaporating solutions of selenion dioxide in alcohol and aniline in ether, but only in absence of water. Water at once decomposed the salt into alcohol and the acid selenite of aniline.

The production of ethyl ammonium selenite acquires interest from the fact, that it can only be effected in the entire absence of water, to the action of which the salt is very

sensitive. The salt is also of interest because, in mode of formation and in properties, it closely resembles ethyl ammoniumsulphite (see preceding paper), although the work of Michaelis and Landmann (*Ann.*, 1887, **241**, 150) seems to have established that nothing analogous to a sulphonic constitution presents itself in alkyl selenites. One of us has also pointed out (*J. Chem. Soc.*, 1886, **49**, 585) some special points of similarity of silver and mercury selenites to silver and mercury sulphites, although their alkyl derivatives are differently constituted (Michaelis and Landmann, *loc. cit.*).

The selenion dioxide for making the new salt was prepared from selenion of high purity, which had been obtained, years ago, from the 'red sulphur' of Japan, by M. Shimose and one of ourselves. The anhydride being very hygroscopic, special care had to be taken to ensure its freedom from hydration when used. The selenion was dissolved in nitric acid, the solution evaporated to dryness, and the residue repeatedly moistened with water and dried again by heat. The resulting selenious acid was kept for some time, in an open dish, close to the subliming point of the anhydride. Thus almost dehydrated, it was transferred hot to a glass tube in which it was several times sublimed in a current of dry oxygen. Finally it was again volatilised into and deposited in the well dried experimental vessel itself.

Great care was also taken to dry the alcohol in the usual way and then to keep it almost out of contact with the air. The ammonia too was well dried, not so effectively, perhaps, as the alcohol and anhydride, yet sufficiently so, as the result of its use proved.

The selenion dioxide with about five times its weight of

alcohol was treated with ammonia, in a freezing-mixture, until the gas passed unabsorbed. The ammonia causes the undissolved selenion dioxide to dissolve slowly, and the final product is a clear viscid liquid. This liquid, which is most sensitive to the decomposing action of the moisture of the air, can be dried up in a vacuum into a solid with silky lustre, but not to be got, in this way quite free from alcohol. Instead, therefore, of evaporating the liquid, it was poured into a small flask of well-dried ether, with as little exposure to air as practicable. The liquid does not dissolve in ether but, on shaking, the ether extracts the alcohol from it and leaves the solid salt adhering to the flask. After decanting off the ethereal solution and exposing the open flask for a night in a vacuum-desiccator, the salt was obtained dry and was then weighed in the flask.

The analysis was begun by dissolving the salt, in the flask itself, in water acidified with sulphuric acid. The solution, only slightly acid, was distilled for the alcohol, this being then estimated from the weight and specific gravity of the distillate. Distillation of the solution with alkali gave the ammonia, the residue being then heated at 150° for some hours with hydrochloric acid, again distilled with alkali, and no more ammonia got. The selenion was determined by precipitating it with sulphur dioxide in presence of much hydrochloric acid, heating to 100° , and collecting the selenion on a weighed filter. The mother-liquor, after concentration, gave no more selenion with sulphur dioxide.

The percentage numbers obtained were —

$C_2H_5(NH_4)SeO_3$: sel. diox., 63.79; ammonia, 9.77; alc., 26.44.

Found: ,, 64.09; ,, 9.31; ,, —

 ,, ,, 65.94; ,, 10.09; ,, 24.16.

The deviations of the quantities found from those calculated are clearly attributable to slight decomposition of the salt by moisture into alcohol lost and acid ammonium selenite.

Ethyl ammonium selenite is crystalline, soluble in alcohol, insoluble in ether, exceedingly deliquescent, and at once decomposed by water into ammonium hydrogen selenite and alcohol. It cannot be heated or even kept long without decomposing, selenion being one of the products. Thus, after ten days or so in the desiccator, the decomposed salt may contain as much as 5 per cent. of its weight of free selenion, oxidised alcohol (acetic acid?) and ammonia having volatilised.

Non-existence of amidoselenites (selenosamates).

Since it is not easy to get normal ammonium selenite from its aqueous solution, on account of its great solubility and the readiness with which it loses much of its ammonia, Berzelius, Muspratt, and others have all had resort to an alcoholic solution of selenious acid, from which to precipitate the salt by gaseous ammonia. Now, when an alcoholic solution of ethyl ammonium selenite is exposed to moist air or mixed with a very little water, separation of ammonium selenite at once occurs, either normal or acid, according as much ammonia is present or not. The same behaviour has been noted by Hinsberg in an alcoholic solution of ethyl phenylammonium selenite. Moreover, the alcoholic solution of ethyl ammoniumsulphite behaves in a quite analogous way (see preceding paper). Accordingly, we have found that, unless precautions are taken to specially dry the materials and to exclude aerial moisture, the passage of ammonia into a solution of selenion dioxide in good ordinary absolute

alcohol very soon causes ammonium selenites of varying composition to precipitate. We are thus brought in contact with the experimental work of Cameron and Macallan (*Proc. Roy. Soc.*, 1888, **44**, 112), who obtained just such a precipitation by passing ammonia into a solution of selenion dioxide in absolute alcohol, the ammonia being described as having been carefully dried by passing it through a series of potash tubes. But the examination they made of their product and of a derivative of it led them to consider the two substances to be amidoselenites or selenosamates, and not merely selenites.

We have analysed and in other ways examined the products we have obtained in this way. The crystalline precipitate in presence of excess of ammonia is diammonium selenite and can be rendered dry and anhydrous, without decomposing it, in a potash desiccator, charged with a strongly ammoniacal atmosphere. It is a very alkaline and very deliquescent salt, which yields half its ammonia when its aqueous solution is distilled to a small volume. Exposed in a sulphuric-acid desiccator for 20 or 30 hours, it also loses half its ammonia, becoming the half-acid salt. Left for several months in such a desiccator, occasionally opened, it becomes the three-fourths-acid selenite. The results of the analyses of the three salts were very satisfactory, and were obtained when, so to speak, we did not know exactly what we were analysing. They are given as parts per hundred, in the following table:—

$(\text{NH}_4)_2\text{SeO}_3$:	selen. diox.,	68.09 ;	ammonia,	20.87
Found:	„	67.96 ;	„	21.02
$(\text{NH}_4)\text{HSeO}_3$:	„	76.03 ;	„	11.64
Found:	„	76.01 ;	„	10.88
$(\text{NH}_4)\text{H}_3(\text{SeO}_3)_2$:	„	80.73 ;	„	6.18
Found:	„	81.51 ;	„	6.22

It must be mentioned that the numbers for the selenion dioxide in the above two acid selenites differ very little, each to each, from those calculated for Cameron and Macallan's two selenosamates, while those for the ammonia are entirely out of agreement. But as these chemists adopted a method of questionable accuracy for determining the selenion, much weight cannot be laid upon these coincidences.


Now, we have tried repeatedly but fruitlessly to get these selenosamates, or any other salts which might be amido or imidoselenites. Some years ago, also, Mr. Toyotaro Kamiya tried, in this laboratory, to prepare Cameron and Macallan's selenosamates, at the instigation of one of us, who then wanted to see whether the acid salt, $(\text{NH}_4)\text{H}(\text{SeO}_2\text{NH}_2)_2$, might not be diammonium imidoselenite $\text{HN}(\text{SeO}_2\text{NH}_4)_2$, instead. But Mr. Kamiya reported failure to get products of uniform composition, or any having the composition of Cameron and Macallan's salts, or any which did not readily yield up all their nitrogen as ammonia when boiled with potassium hydroxide. To Mr. Kamiya we are indebted for the preparation and analysis, above given, of the salt which proved to be the three-fourths-acid ammonium selenite.

Having failed in our attempts to confirm the observation of Cameron and Macallan that dry ammonia causes precipitation in a solution of selenious anhydride in absolute alcohol; having obtained in these attempts only a very soluble salt, ethyl ammonium selenite; and having got precipitation, apparently such as theirs, only when moisture had in some way entered in, which precipitation was, however, of ammonium selenites only, we may proceed to point out what a lack of reliable evidence there is contained in their paper, for the existence of these salts.

In just such ways as the more acid ammonium selenite can be prepared from the normal or the less acid selenite, did Cameron and Macallan get the acid selenosamate from the normal selenosamate. No property of the selenosamates is recorded by which they are distinguishable from the acid selenites. It is indeed stated that a neutral solution gives hardly any precipitate with barium chloride until ammonia is added, but then that is equally true of a neutral solution of ammonium selenite, the normal salt being strongly alkaline.

The only difficulty, but it is a great one, in the way of regarding the selenosamates as being merely selenites lies in the fact that the quantities of ammonia found in the two salts are just those proper to the selenosamates and not in the least those proper to the selenites. This difficulty, we believe, may be legitimately surmounted, until further evidence is forthcoming, by calling in question the propriety of the methods of analysis by which such results were reached. In the first place, the normal selenosamate, described as continuously losing ammonia, was dried for analysis in a partial vacuum over sulphuric acid, and yet gave the right proportions of both selenion dioxide and ammonia very closely indeed. Secondly, the selenion dioxide was estimated by passing chlorine into the solution of the selenosamate and then precipitating barium selenate; it was therefore estimated by a method which H. Rose in 1861 (*Pogg. Ann.* **113**, 472; *Z. anal. Ch.*, **1**, 75) had condemned as being quite unsatisfactory and utterly unreliable for reasons given, and which has again been discredited by Boutzoureano (*Ann. Chim. Phys.*, 1889 [6] **18**, 296) as being far from giving good results. Lastly, they record no attempt to estimate the ammonia by direct distillation with alkali and give no reason for not

employing this method. Instead, they tried Kjeldahl's nitrogen process, which they found to give excellent results with one selenosamate but to be unsuitable for use in the analysis of the other. They offer no explanation of this remarkable difference, and we have to rely, without evidence, on the accuracy of the process in one case, though in the other indistinguishably similar case it is found to be unsuitable. After failing also in the use of the soda-lime process to determine the ammonia in the acid selenosamate, success was at last gained by using Dumas' nitrogen method. The chloroplatinate method was tried with both salts and gave indefinite results. It is certain that Cameron and Macallan, in some of their analyses of the acid selenosamate, got quantities of ammonia much below what they expected, thus favouring the supposition that this salt may have been the three-fourths-acid selenite. However that may be, we hold ourselves justified in asserting that there has not yet been given any reliable evidence that selenion dioxide and ammonia in presence of alcohol or water give any other compounds than selenites. It may, therefore, be said of selenion dioxide that, unlike sulphur dioxide, it forms only oxylic salts, whether with alkyl radicals, with amines, or with metals.



Notes on the Minerals of Japan.

BY

Kotora Jimbō, *RIGAKUHAKUSHI*,

Professor of Mineralogy, Science College, Imperial University, Tōkyō.

Through the kindness of Mr. Tsunashirō Wada, I have been allowed to study his collection of Japanese minerals, which surpasses all others of the kind both in magnitude and completeness. Moreover, he has given me much necessary assistance and advice in writing the present notes, which consist of short accounts of the characters and occurrence of minerals in Japan, with special reference to his collection. I wish therefore to express here my most cordial thanks to him.

Next to Mr. Wada's collection, are to be mentioned that of the Science College of the Imperial University of Tōkyō, that of the Imperial Museum in Ueno, Tōkyō; and those of Messrs. Kō, Sasamoto and others; as being the most important collections of Japanese minerals. Papers connected with these specimens are scattered through the Journal of the Geographical Society of Japan, begun in 1889; the Journal of the Geological Society of Tōkyō, begun in 1893; the Journal of the Science College, Tōkyō, begun in 1888; and other Japanese periodicals; besides well-known foreign publications containing mineralogical descriptions.

In the present notes, all crystal faces are treated according to Dana's System of Mineralogy; and all Japanese names are transliterated according to the rules made by the Society for romanising the writing of Japanese. Thus, all vowels are pronounced as in Italian, and all consonants as in usual English spelling. Special care must be taken to distinguish long vowels marked with $\bar{}$, as in *Ōta* and *Ota*, which are two fundamentally different names in Japanese.

The statement of mineral-localities has usually been restricted to the names of the village and province; for more exact and detailed statements, the reader is referred to the catalogues of Japanese minerals, &c., in the Imperial Museum, of those exhibited in the Chicago Exhibition, or of those sent to the International Geological Congress of 1897.

Authorities are mentioned in the case of many minerals; but references to periodicals published in Japanese have been omitted.

A. Elements.

1. Graphite.

Province HIDA contains many localities of graphite and is known as the principal source of this mineral in Japan. According to Ishiwara it forms impregnations in biotite-gneiss. A peculiar occurrence of graphite in the shape of round masses in a dioritic rock is found in the Piboro river in Tokachi Province. Suzuki has given a list of graphite localities in Japan.

2. Sulphur.

SHIRANE Volcano in Kōzuke.—Iwasaki has described sharp-

pointed pyramidal crystals of sulphur from a solfatara of Manza on the western flank of the volcano. The individuals attain a length of 1.5 cm. along the c axis, show the faces, oP , P , $\frac{1}{3}P$, ∞P and a brachydome, and carry terraced depressions on P , which are due to imperfect development of crystals. Numerous minute elliptic depressions on this face may be due to etching.

In 1898, I found, at the same place, less numerous but more perfect crystals showing a short-columnar habit. Their size is smaller than one fourth of the above mentioned specimens; the faces are, however, more numerous.

KOBUI in Oshima Province.—On the western side of the volcano Esan, a brownish-grey compact sulphur is found forming thin layers in a grey tuff, in which we find, besides the stratified specimen, quite irregular aggregates of ordinary yellow sulphur (Jimbō's observation 1889).

YONAGO in Shinano Province gives orange-red tellurium-sulphur, while TATEYAMA-JIGOKU in Etchū Province and the island IWŌJIMA near the province of Ōsumi are localities of selenium-sulphur.

The KOSAKA mines in Rikuchū.—Small crystals of sulphur with numerous faces are found in the metallic veins containing copper, silver, &c.

3. Arsenic.

AKATANI in Echizen.—As described by Beck in *Tschermak's Mittheilungen*, 1897, and previously mentioned in the *Zeitschrift der deutschen Geologischen Gesellschaft*, 1895, the native arsenic of this place is found in the shape of globular as well as quite irregular groups of numerous rhombohedral crystals showing their poles outside. Their edges are usually rounded and their surfaces roughened and tarnished. The centre of the aggregate

consists of concentric spherical shells of arsenic. The separate rhombohedra are about 0.4 cm. long, and the diameter of the aggregate is usually less than 4 cm.

4. Bismuth.

At KANAGASE in Ikuno in Tajima Province we find bismuth filling up interstices of botryoidal quartz-aggregates found in silver ores.

At ŌKURADANI in Obira in Bungo Province, thin lamellæ of bismuth are found in the cleavage of a light rosy-coloured fluorite.

5. Platinum.

The occurrence of minute black grains of platinum was reported by Ishikawa, &c. from the wash-gold of TUNAKBETS, a tributary of the Sorachi river in Ishikari Province; and also from that of the upper course of the Yūbari river in Iburi Province.

6. Iridosmium.

This metal was mentioned by Ishikawa, &c., in the form of flattened minute grains, found with the above mentioned platinum. Another locality for iridosmium is the gold placers of the river YOSHINOAWA in Shikoku.

7. Copper.

Beautiful crystal groups of copper with numerous but hardly determinable faces occur in the mines of OSARUZAWA and KOSAKA in Rikuchū, of ARAKAWA in Ugo Province, &c., where irregular, platy, moss-like and other aggregates are also observed with associated cuprite.

8. Silver.

Minutely platy and other forms of silver are found in the gold mines of YAMAGANO in Ōsumi Province and of KAGO in Satsuma Province, besides at KOSAKA in Rikuchū, &c., (according to Kō).

Wada possesses a specimen of long hairy silver from TASEI in Ikuno in Tajima Province.

9. Mercury.

Mercury occurs, according to Harada and Ōtsuka, in the two provinces HYŪGA and AWA (Honshū).

10. Gold.

ASAHI near Ikuno in Tajima.—Beautiful groups of minute crystals, as well as feather-like aggregates are found in the gold mines.

YAMAGANO in Ōsumi.—In the mines of Yamagano, there was found a minute hexagonal plate of gold about 0.4 cm. in length, now in Wada's collection. It carries a few straightly truncated triangular pyramids on its hexagonal face.

Scaly, platy, hair-like and other forms of gold aggregates are often found in some Japanese gold mines.

11. Meteorites.

The meteorite of OGI in Hizen was described by Divers in 1882, that of TAJIMA treated by Korschelt in 1881, and that of KESENGŌRI in Rikuzen by Ward in 1893. (See Wenckstern's Bibliography, 1895, for the literature of Japanese minerals written in European languages). A few notes on Japanese meteorites are found in the Journal of the Geographical Society and in that of the Geological Society of Tōkyō, both published in Japanese. The specimens accessible to me are: two from FUKUTOMI in Hizen, two

from MAEME and another place in Ōsumi Province, one from ŌSHIMAMURA in Satsuma Province, and one from SAKARI in Kesengōri (all these specimens are preserved in the Imperial Museum), besides two others fallen in 1897 in the neighbourhood of the town of Yamaguchi in Suwō Province.

B. Sulphides, &c.

12. Realgar and Orpiment.

Beautiful minute crystals of realgar are found at MONJI in Rikuzen Province; from this locality Wada obtained a good crystal of this mineral about 2 cm. in length but already broken to pieces by exposure to sun-light.

Massive realgar and coarse platy orpiment were collected in a tuff near the hot springs of JŌZANKEI in Ishikari Province.

13. Stibnite.

ICHINOKAWA in Iyo Province.—The large well-known crystals of stibnite, formerly found at the mines of Ichinokawa, are often more than 50 cm. in length; but such good specimens are now very rare. As described by Ogawa, Iwasaki, &c., the stibnite veins are found there in a conglomerate as well as in the crystalline schists of Kotō's Sambagawa Series (Journal of the College of Science, Tōkyō, 1888), attaining a thickness of 25 cm. Associated with this mineral we find quartz and calcite crystals. The stibnite is often in fine needle-like aggregates, but good measurable crystals give very numerous crystal faces enumerated by Dana, who has given all details of characters of this mineral as it occurs in Iyo.

Other occurrences of stibnite are the provinces HYŪGA, KII, &c.

14. Bismuthinite (?).

A fine needle-shaped aggregate of grey colour, rarely found with bismuth, fahlore, &c. in the silver veins of IKUNO in Tajima is probably of this mineral.

15. Molybdenite.

Six-sided platy crystals as well as irregular plates (sometimes attaining 6 cm. in length) of this mineral are found in the provinces IZUMO, ECHIGO, HIDA, &c. The small plates about 0.5 cm. in diameter, found in the crystalline limestone of Kamioka in Hida, are very pretty.

16. Zinc-blende.

Kō mentioned the occurrence of beautiful and large crystals (sometimes more than 7 cm. in diameter) of zinc-blende in the mines of KURATANI in Kaga Province, of ANI and ARAKAWA in Ugo Province, of OSARUZAWA in Rikuchū Province, of ADAKAI in Izumo Province, &c. The crystal faces are usually only $\pm \frac{O}{2}$ and ∞O , but specimens from Ani, which sometimes exceed 4 cm. in diameter, also often shows $\infty O \infty$, &c. Polysynthetic twins on O are quite numerous at Ani and Kuratani, while similar twins of usually two or three individuals occur at the UCHINOKUCHI mines in Bungo Province. Wada possesses a druse of tetrahedral zinc-blende crystals, about 1 cm. in diameter and brought from the DAIRA mines in Ugo Province. The edges of the tetrahedra are beveled with $\infty O \infty$, and the solid angles with very small faces of negative tetrahedra.

All the above-mentioned localities of zinc-blende usually give the dark-brown to brownish-yellow varieties.

A parallel growth of minute copper-pyrite crystals, on dark-brown zinc-blende individuals, is found at KAYAKUSA in the mining district of Ani. From this region, we found optically anomalous specimens of zinc-blende, showing dark brown stripes in yellow-coloured cleavage-pieces, beside numerous thin lamellæ with double refraction under the microscope.

Thick deposits of the mineral are found in the mines of KAMIOKA in Hida Province.

Manganese-bearing zinc-blende found in the SAIMYŌJI mines in Ugo Province is massive, dark-brown coloured and nearly opaque. It is associated with rhodocrosite besides a little pyrrhotite, &c.

17. Pyrrhotite.

BIZEN and other provinces in the western part of HONSHŪ, besides the province of ECHIGO, &c. are the localities of massive pyrrhotite in metallic ore deposits.

18. Pyrite.

Beautiful crystals which are usually not rich in faces are found according to KŌ, in the mines of UDO, ADE and ADAKAI in Izumo Province, of OSARUZAWA in Rikuchū Province, of ANI and ARAKAWA in Ugo Province, of OGOYA in Kaga Province and of FUTTO in Mikawa Province, besides in OGASAWARAJIMA (the "Bonin Islands" of foreign maps) and other places. The crystals sometimes attain 6 cm. in diameter.

UDO (according to Hiki's description).—Beautifully shining crystals of pyrite, often about 3 cm. in diameter, are here found mostly in the combination $O. \infty O \infty$, but sometimes in $O. \infty O \infty. \left[\frac{\infty O 2}{2} \right]$.

We find also the faces ∞O and $\left[\frac{mO_n}{2}\right]$. Simple octahedra are seldom met with. Striations on O and $\infty O \infty$ are due to oscillatory combinations of these faces with ∞O and $\left[\frac{mO_n}{2}\right]$, as in the specimens from Ogasawarajima, Osaruzawa, Ani and Arakawa. Striations on $\left[\frac{\infty O_2}{2}\right]$ are mostly parallel to its regular edges, but in rare cases perpendicular to them. Besides there are striations on $\infty O \infty$, running parallel to $\left[\frac{\infty O_2}{2}\right]$ and $2O_2$. Each crystal is developed usually on all sides, for it is found in a clay vein.

OGOYA.—Pyrite crystals which are here found with copper-pyrite, &c. show O , $\infty O \infty$, $\left[\frac{\infty O_2}{2}\right]$, $2O_2$ and $\left[\frac{mO_n}{2}\right]$; and have an octahedral habit usually with very subordinate $\left[\frac{\infty O_2}{2}\right]$, &c. The individuals of pyrite attain 2 cm. in diameter.

TŌHIRA in Rikuchū Province.—The specimens of pyrite from Tōhira, described by Hiki, show a peculiar rhombohedral habit on account of the development of only six of the dodecahedral faces. The crystal-form is nothing but $\left[\frac{\infty O_2}{2}\right]$. $\infty O \infty$. The size of individuals is sometimes more than 2 cm. in length.

Quite a similar form of pyrite is seen at AKADANI in Echigo Province, where the largest individual is about 4 cm. in length and the crystal developed on all sides, as at Tōhira.

Good specimens of supplementary twins of dodecahedra were found in OGASAWARAJIMA and at ANI(?).

The face of $\frac{3}{2}O$ was only observed in a specimen from ŌHINATA in Shinano.

19. Marcasite.

Botryoidal aggregates and crystal groups of marcasite were collected in the AIKAWA mines in Sado. Small spherical or

irregular rounded aggregates in the clay of KAMISHINA in Shinano are either pyrite or marcasite.

20. Arsenopyrite.

Kō mentioned the occurrence of nearly perfect crystals of arsenopyrite ($\infty P. \frac{1}{4}P\infty$) in the mines of KURATANI in Kaga, FUTTO in Mikawa, KAMIOKA in Hida, SASAGATANI in Nagato, and KOHAGI and BANDŌ in Echizen. Twins are quite numerous at Kuratani and Futto.

Among the small perfect crystals of arsenopyrite from AWASHIRO in Mikawa, Fukuchi found many twins on ∞P and those on $P\infty$, besides simple individuals ($\infty P. \frac{1}{4}P\infty$). There are also found trillings on $P\infty$.

21. Galena.

Pretty crystals with bright faces, usually showing only O, $\infty O\infty$ and ∞O are found in the mines of KURATANI in Kaga and of ANI in Ugo. The crystals from the former locality with prevailing O and subordinate $\infty O\infty$ are often rounded on edges, holed on O, and covered with microscopic etching figures. A peculiarly zonal appearance is observable on account of this natural etching, which had produced indistinct terraces on the almost smoothly rounded crystal edges.

22. Argentite.

Wada possesses octahedral (?) crystals of this mineral from the mines of AIKAWA in Sado and of INNAI in Ugo. Their faces are really very hard to determine. KANAGASE in the Ikuno mining district in Tajima gives, though rarely, imperfect crystals of argentite.

23. Chalcosite.

Massive chalcosite is found at OSARUZAWA in Rikuchū, &c.

24. Cinnabar.

The principal localities for cinnabar in Japan are KOMA-GAESHI in the Yamato Province, HIRADO in Hizen Province, ISE Province, AWA Province (in Shikoku), TSUKIYOSHI in Iyo Province, &c. Very minute crystals are sometimes observed with the help of a lens.

25. Bornite.

This mineral is found in massive state in many copper mines of Japan, especially in those of OMODANI in Echizen Province.

26. Chalcopyrite.

Chalcopyrite is worked in most Japanese copper mines, among which those of ANI, ARAKAWA, OSARUZAWA, OGOYA, ADE, &c., give good crystals, usually showing only $\frac{P}{2}$, but sometimes $\frac{P}{2}$ and $\frac{mP_n}{2}$.

A small flattened crystal of this mineral from the ASHIO mines in Shimotsuke Province, a curious triangular wedge-shaped crystal from Arakawa (Wada's collection), and numerous complicated twin-like forms (somewhat resembling Fahlore twins on O, with a projecting part on some of the tetrahedral faces) found at Ogoya, Ani and Osaruzawa, are still unsolved problems in the determination of crystals of Japanese chalcopyrite.

27. Matildite.

A nearly compact aggregate of this mineral was found with native gold in a mine of KURIYAMA near Nikkō in Shimotsuke

Province. The matildite is here associated with argentiferous galena in a quartz vein.

28. Jamesonite.

This mineral is found as feather-ore in association with galena and rhodocrosite of KURATANI in Kaga, and with arsenopyrite, &c., of TSUGU in Mikawa. In the Hosokura mines in Rikuzen Province, there are found loose botryoidal aggregates of short fine needles, of a purple-grey velvety appearance. They were determined as jamesonite.

29. Pyrargyrite.

Pyrargyrite is found in the mines of IKUNO in Tajima, as well as in the INNAI mines in Ugo, &c. Small prismatic and other crystals are found rarely in KANAGASE, &c., belonging to the Ikuno mining district.

30. Fahlore.

Copper-fahlore is found in the AIKAWA, KURATANI and KANAGASE mines. Crystal faces observed in these fahlore specimens are $\frac{O}{2}$, ∞O , $\frac{mOm}{2}$, &c. The size of individuals is always small.

31. Stephanite.

Massive specimens as well as small hexagonal plates and short prisms of this mineral are found in the mines of INNAI in Ugo, IKUNO in Tajima and HANDA in Iwashiro Province.

32. Stannite (?).

Kochibe mentioned the occurrence of this mineral in the mines of SAKURA in Harima Province, KANAGASE in Tajima, TANIYAMA in Satsuma Province and Obira in Bungo.

C. Oxides.

33. Quartz.

The principal localities of quartz crystals in Japan are as follows :—

(1.) Several places near Kōfu (as MITAKE, OTOMEZAKA, KAMIKANE, TAKEMORI, KAWAHAKI &c.),—rock-crystals, often containing liquid cavities and various mineral enclosures.

(2.) Several localities at and near TAKAYAMA in Mino Province,—smoky quartz.

(3.) TANOKAMIYAMA in Ōmi Province,—smoky quartz.

(4.) The mines of AIKAWA in Sado Province,—rock-crystals with numerous negative crystals and liquid cavities.

(5.) OHARA in Iwaki Province,—amethyst.

(6.) KURODAKE in Etchū Province,—rock-crystal.

(7.) FUJIYA, &c., in Hōki Province,—amethyst and smoky quartz.

At the localities mentioned under (1) quartz crystals are mostly found in granitic regions, but their paragenesis is not well known.

At (2) and (3), quartz crystals are found in pegmatite masses in granite, in association with micas, albite, potash-felspars, topaz, beryl, tourmaline, &c. Cassiterite, sapphire, rutile (?), wolframite, magnetite, fluorite and fergusonite are found in rivers at (3), while secondary minerals as manganese oxide are quite frequently found at both of these localities. Our material is not sufficient for the discussion of mineral successions in these occurrences ; though, as mentioned later on, we have already some knowledge of the age of different micas and of the two generations of topaz crystals in Tanokamiyama.

In the tertiary tuffs of the Aikawa mines (locality 4), rock-crystal is found in veins of sulphuretted ores ; and in the garnet-rock of Kurodake, the same mineral is found together with various garnet-crystals, magnetite, pyroxene, &c. At Ohara, amethyst occurs in coarse-grained rhyolite ; while at Fujiya the mineral is found with smoky quartz in mountains of granite and other rocks.

Japanese quartz is often found as Dauphiné twins, as for instance the smoky quartzes of the provinces of Ōmi, Hōki and Mino, and the rock-crystals of the provinces Kai and Etchū.

Twins of rock-crystals on P_2 are not very rare at Otomezaka, Takemori, Kawahake, &c. near Kōfu ; and on the island NARUSHIMA belonging to the Gotō group, lying off the coast of Hizen. Those of Narushima usually attain a length of 2 cm., while those from the environs of Kōfu are much larger. Two largest specimens from the latter, one in the science college and the other in Wada's collection, are nearly 25 cm. long. In the specimens from the region near Kōfu, we find clefts parallel to the c axis and perpendicular to the broadest faces of individuals. Two individuals united on P_2 are in very rare cases normally developed, instead of being flattened as usual. The small twins of Narushima are quite simple in combination, there being rarely found any trapezohedral face on them.

The Brazilian twins are quite frequently observed in rock-crystals collected near Kōfu, in the Aikawa and Innai mines, at Kurodake in Etchū, at Amagisan in Izu Province and at Katsudo in Tosa Province, also in the light-grey quartz from Tanokamiyama, in the smoky quartz of Mino and of Moraiyama in Shinano Province, and lastly in the amethysts of Ohara and Fujiya.

Double twins have been observed in two pretty regularly developed, dark-smoky quartz crystals from Mino, and in many rock-crystals found near Kōfu which are twins on P_2 . The former two specimens are Dauphiné twins, which show Airy's spirals in cross sections; Fukuchi recognised in them, a complicated distribution of electric poles after an experiment with pyro-electricity. In the specimens taken near Kōfu, there are very often found Dauphiné twins, again united on P_2 .

In the Brazilian twins above enumerated, the twin-structure was always observed in interference-figures and not in the characteristic distribution of trapezohedral faces.

Ordinary rock-crystals of Kai are sometimes more than 15 cm. in the diameter of basal sections; but individuals large enough to yield a perfectly clear colourless sphere of as much as 13 cm. diameter, such as are sometimes to be found in private collections, are no longer now to be had.

Quartz crystals showing $\pm R$, ∞P , $4P$, $2P_2$, $6P_3^2$, $4P_3^4$, &c. occur in larger crystals at the localities 1, 2, 3, 6 and 7. Many specimens from these localities show straight prismatic edges and nearly equal-sized rhombohedral faces. Crystals with rhombohedral terminations and curved prismatic faces are found in the amethyst of Ohara, and in rock-crystals of Aikawa and other metal mines. Trapezohedral faces are usually found on larger individuals, sometimes however on smaller ones; they are very seldom met with on the small twins on P_2 from Narushima. Corrosion-faces were numerous on a naturally etched smoky quartz from Kamikane in Kai, which will be treated of later on.

Parallel growth is frequently found in the quartz of Tanokamiyama, where smoky quartz is often surrounded by a zone of white or colourless quartz in the form of a complete cover.

On this outer shell there are often attached dark-purple or grey, simple but regularly formed, small individuals ($\pm R. \infty R$), which are all nearly parallel in orientation to the main crystal. In Wada's collection, there is found a large smoky quartz from Fujiya, about 20 cm. in diameter of basal section and surrounded by small individuals of amethyst, which are all nearly equal in thickness and whose rhombohedral faces are parallel to those of the main crystal. These amethyst crystals may form a perfect shell over it, when their interstices are filled up with amethyst substance.

Zonal structures, already mentioned in connection with Tanokamiyama, are also quite frequent in the crystals from Aikawa, Fujiya, &c. At Aikawa, the structure is produced by an unequal distribution of liquid enclosures; at Fujiya, &c., by different colourations and optical characters of different zones. Such zonally composed quartz crystals from Tanokamiyama, Aikawa, Kai, Fujiya, &c. frequently show biaxial interference-figures; moreover, right-handed and left-handed as well as spiral interference-figures are sometimes found in different zones of one crystal.

Enclosures of liquid, often with gas bubbles, are quite numerous in the rock-crystals of Aikawa and Kai, which often show biaxial interference figures. The smoky quartz of Tanokamiyama contains liquid enclosures, in which Kō has observed certain mineral crystals. The smoky quartz of Tanokamiyama, Takayama, &c. rarely enclose minerals; tourmaline and, in one or two cases, garnet also were found in the specimens from Tanokamiyama. Liquid enclosures are also found in the amethysts of Ohara and Fujiya, and in the rock-crystals of Innai, Kurodake, &c. Specimens from Ohara sometimes

show in basal sections a peculiar distribution of liquid cavities, by which white and purple sectors with edges parallel to the hexagonal sides are produced. Mineral enclosures are very numerous in the rock-crystal from Kai and consist of tourmaline, actinolite (?), pyrite, epidote (?), &c.; sulphur was found in one or two specimens. Grey-coloured minute spheres are enclosed in the rock-crystal of Kurodake and in the amethyst of Ohara.

Natural etching figures on a smoky quartz crystal from Kamikane in Kai Province, are essentially similar to those described by Molengraaf in Groth's *Zeitschrift*, 1888. The triangular depressions on $\pm R$ measure about 0.07 cm. along their longest side (larger holes of this kind were discovered by Kō in the smoky quartz of Mino Province). The depressions on ∞P are not so distinct as in Molengraaf's descriptions; long triangular scratches and rectangular hillocks on $\frac{mP_n}{4}$ seem not to have been found in his specimens; besides there are found on some crystal edges irregular grooves, which are not at all mentioned by him.

A smoky quartz from TENJINBARU in Obira in Bungo Province bears triangular etching figures on $\pm R$ as in the specimen from Kamikane.

The rock-crystal of KURODAKE shows a kind of etched depressions on ∞P , not like those in Molengraaf's description. Polygonal (mostly four-sided) depressions on the rhombohedral faces of quartz from Kawahake in Shinano Province, collected by Hoshina, &c., are also most probably referable to etching. Minute flat hillocks, whose triangular bases are bounded by slightly curved lines, are very numerous on the roughened part of rhombohedral faces in the smoky quartz of Hōki. These hillocks are more pointed in outline, than those produced by

ordinary vicinal faces on $\pm R$ and are conjectured to be due to etching.

Chalcedony and agate are chiefly found in the provinces KAGA, ETCHŪ, IZUMO, &c. Dark-green to green compact quartz is found in the provinces of IZUMO, ECHIGO, &c. All these occurrences of quartz varieties have been described by Ōtsuka, Hiki, &c.

Pseudomorphs of quartz after calcite in ∞P , ${}_0P$ were found at OSAWA near Nikkō in Shimotsuke Province; those after sharp-pointed rhombohedra of calcite were found in MINO Province. Top-shaped chalcedonies from the provinces of UZEN, ECHIGO, &c., seem to be pseudomorphs after broken pieces of some spherical mineral-aggregate with radial-fibrous structure and consist of two flat cones united at bases. They have a diameter of about 1 to 1.5 cm. The apex of the cones is provided either with a rounded prominence or a depression. For the pseudomorphs of quartz after barite, see under Barite.

34. Tridymite.

In the stone-quarry of Gōroyama close by the town of NAGANO in Shinano Province and in that of SHIMAZAKI on the west of Kumamoto in Higo Province, there exist andesite exposures with loose enclosures and segregations. In these rocks tridymite is abundantly found as irregular scales and tabular crystals. Associated with it are found a few breislakite (?) needles in some of the specimens from these localities. At Gōroyama, Yamasaki has observed a very pretty trichroic cordierite crystal of very minute size. Tridymite from Shimazaki is usually more transparent than that from Gōroyama, although the characteristic optical anomaly, as well as twinning crystal-

forms, is equally well observable in specimens from both places.

The occurrence of Tridymite at Maekakeyama, a part of ASAMA Volcano, is rather rare.

35. Rutile.

Of this mineral a single bad specimen of prismatic form, and another small crystal, both from TAKAYAMA in Mino Province, are found in Wada's collection. They are of a dark brown colour.

36. Cassiterite.

TAKAYAMA, &c., in Mino.—The tin placers of this granitic region, which are now nearly exhausted, gave wolframite, sapphire, fergusonite, magnetic iron sand, topaz crystals with rounded edges, &c. Many of the larger specimens of cassiterite are about 1 cm. in diameter, but mostly smaller. They have sometimes quite well preserved edges and show the usual cyclical twins on $P \infty$.

TANIYAMA in Satsuma Province.—In the tin mines of this locality cassiterite is found in massive form and associated with wolframite.

KIURA in Bungo Province.—Here, cassiterite crystals are found in a brown-coloured detritus filling up cavities in crystalline limestone; massive specimens of cassiterite are also found along with arsenopyrite, &c., in veins through limestone, hornfels, &c.

HITACHI Province.—Wada possesses a beautiful druse of crystals of cassiterite, each about 1 cm. in diameter; it is said to have been obtained at TAKANO in this province.

37. Pyrolusite.

See Psilomelane.

38. Corundum.

TAKAYAMA in Mino Province.—From tin placers of this locality were formerly collected flat hexagonal pieces and more columnar grains of blue to bluish-white corundum. Their diameter is less than 1 cm. The parting parallel to *oP* shows concentric zones and radial stripes of white colour. The different zones are sometimes distinguished by uniaxial and biaxial characters of interference figures.

39. Hematite.

The principal hematite localities of Japan have been studied by Ōtsuka, &c., who determined the extent of the specular iron deposit at SENNIN in Rikuchū, AKATANI in Echigo, &c. The mineral is found either in massive forms, or as small, flat crystals with rhombohedral and prismatic faces.

The occurrence of titanite iron, which accompanies magnetic iron sand from different provinces in Japan, has not yet been specially studied.

40. Cuprite.

Small cubical, dodecahedral and other simple crystals, less than 0.15 cm. in diameter, are found in cuprite masses, associated with native copper at KOSAKA in Rikuchū, ARAKAWA in Ugo, &c.

41. Tenorite.

Kō mentioned small dark-blue six-sided plates, on the black coloured ore ("Kuromono") of KOSAKA in Rikuchū, as being identical with tenorite.

42. Opal.

The most important occurrences of opal in Japan are BODAI in Kaga, the province of IWASHIRO, &c. Some of the specimens show irregular double-refracting bands in thin sections.

Pretty Hyalite spheres of TATEYAMA in Etchū, about 0.2 cm. in diameter, either loose as sand or cemented together into aggregates, were formerly obtainable on the northern shore of a small round lake of hot water, lying about 4 km. to the east of hot-spring hotels. In 1898, I have found only dirty-grey hyalite grains in an ash-like decomposition-product of volcanic rock.

Silicified wood, usually of coniferous species, is found in tertiary as well as cretaceous deposits of several parts of HOKKAIDŌ, (see Jimbō's General Geological Sketch of Hokkaidō, 1892) and also at a number of localities in other parts of Japan.

Diatom-earth forms thick beds in the Tertiaries of HOKKAIDŌ (see the above mentioned work); it is also found in BUNGO Province, &c.

43. Manganite.

Rectangular platy crystals (about 1 cm. long) of manganite, from ASHIO in Shimotsuke province, were found associated with copper-pyrite crystals and drusy quartz. Prismatic crystals (about 1 cm. long) of the same mineral came from the ŌWANI mines in Mutsu Province.

44. Limonite.

Massive limonite is found to some extent at YANABARA in Mimasaka Province. Limonite in the form of roots of plant has been described by Kotō from TAKASHI in Mikawa Province, and occurs also in several other places. Limonite after pyrite,

found in the tuff of TAKESHI in Shinano Province, (shows ∞ O ∞ and $\left[\frac{\infty\text{O}_2}{2}\right]$, and seldom O besides.

45. Asbolane.

This mineral is found in gravels in OWARI Province, whence it is taken for use in porcelain works.

D. Haloid Salts.

46. Cerargyrite.

Wada possesses a crust-like specimen from NUKUMI in Satsuma Province, resembling common cerargyrite in appearance.

47. Fluorite.

The principal localities of fluorite in Japan are ŌKURADANI in Obira in Bungo Province, ISHIGURE in Ise Province, OMODANI mines in Echizen Province, HŌDATSUSAN in Noto Province, &c. The fluorite of Obira is colourless to light rose-coloured, contains bismuth on its cleavage cracks, and forms part of copper veins. That of Ishigure is green or dark-purple coloured and forms veins in granitite; here good crystals, with O alone or with ∞ O ∞ , O and ∞ O, are sometimes found. Octahedral crystals have also been found in the mines of Ashio, &c., while cubical crystals are more common in other localities. The face ∞ O was observed in a single colourless crystal from Obira measuring about 1 cm. in diameter and showing an octahedral habit.

48. Thomsenolite (?) and Ralstonite (?).

Wada possesses a single small specimen said to be from TANO-

KAMIYAMA in Ōmi, showing druses of minute crystals of a white colour. The crystal-forms agree with those of thomsenolite and ralstonite.

E. Carbonates, &c.

49. Calcite.

Good crystals of calcite are found in the metallic veins of ANI, KAMIOKA and of other places. We find, for instance, rhombohedral crystals looking like cubes, at the zeolite-locality of MAZE in Echigo Province, acute and obtuse rhombohedra at ISHIGURE in Ise, and scalenohedral crystals (R_3) in the copper mines of MAZE, ANI, &c.

Calcite containing a little manganese is found in massive state in the INNAI and AIKAWA mines. In the latter place, the mineral sometimes occurs in the form of more or less rhombic plates, covered with minute scalenohedral crystals of the same substance with rounded edges. The thickness of the plate, together with the drusy crystals on both faces, reaches about 0.8 cm. The whole structure resembles scalenohedral crystals, joined together on their lateral edges and arranged in parallel orientation. Kō first described this structure and ascribed it to a simple parallel growth of minute supplementary twins of scalenohedral crystals with a twinning suture at their middle.

Some crystals from KAMIOKA are in the combination $\frac{2}{3}R_2$. R_3 . ∞R and enclose a simple rhombohedron R as the main crystal. (Kō's collection).

Supplementary twins of R_3 are found in the mines of ANI, and FUKOKURA near Osaruzawa; in both of these localities R_3 is also found as simple individuals.

Some crystals from the HANDA mines in Iwashiro are, according to Sakurai, in the form of R_2 (instead of R_3) with peculiarly rounded crystal edges.

Scalenohedral calcite with numerous faces was brought by Saitō, from the zeolite locality of OSAWA near Nikkō.

Prismatic sub-individuals are found upon calcite crystals with $-\frac{1}{2}R. \propto R$ from the zeolite locality of MAZE. In the KOSAKA mines in Rikuchū, the crystals in $-_2R$ are covered by sub-individuals in $-\frac{1}{2}R. -2R$. A reddish-white sharp-pointed rhombohedron of calcite from CHIKUGO Province (in the University collection in Tōkyō) is covered with prismatic sub-individuals in $\propto R. -\frac{1}{2}R$.

Peculiar brownish-grey pseudomorphs of calcite found in the tertiary shale of AOKI in Shinano Province, are of special interest. The shale is well stratified, and in it we have found remains of vertebræ, a skull (about 18 cm. long) and other bones of an animal belonging to Delphinidæ (?), which are all deformed by pressure. The pseudomorphs vary in length from 3 to 13 cm., and their forms are of at least four different types. Hiki has referred two of these to Gay-Lüssite. As chief characteristics of these pseudomorphs, we may mention rough transverse striations like those of oscillatory combinations, the arrangement of individuals parallel to the stratification of the shale with their imperfectly developed edges below, and their frequent grouping in an irregularly branched finger-like figure. Acute pyramidal forms resembling a monoclinic form are most numerous; flattened pyramids with sharp polar edges, very short pyramids with nearly

rounded outlines produced by numerous striations, and prismatic forms with blunt terminations are less frequently found. The number of these pseudomorphs enclosed in the shale is very great; ten or twenty samples of them are easily collected in a few minutes.

Similar specimens occur in marly nodules in the tertiary shale of the PORONAI and other coal-fields in Hokkaidō; also in another state at Ōkōzu in Echigo Province.

Beautiful limestone-caves with stalactites are found at KIURA in Bungo, KAGEMORI in Musashi, &c.

50. Dolomite.

Crystals of dolomite occur rarely in the Aikawa mines; dolomite-nodules and beds are found in the tufaceous shale of NAKAYAMATŌGE near Aikawa. Rhombohedral crystals of the mineral, white to yellowish-grey in colour, are found in the ANI and INNAI mines.

51. Magnesite.

At Yoshinomura in Tosa, magnesite crystals of brown colour were found imbedded in a white talc-like mass.

52. Smithsonite.

In the HOSOKURA mines in Rikuzen Province, there is found massive smithsonite derived from zinc-blende and forming botryoidal aggregates. Drusy crystals are sometimes found on these aggregates. In the KURATANI mines grey-coloured spherical as well as botryoidal aggregates of smithsonite are found, with attached and enclosed individuals of pyrite and zinc-blende. A pseudomorph of smithsonite after calcite ($-\frac{1}{2}R. \infty R$) was brought from the KAMIOKA mines in Hida, where massive smithsonite is found in other forms together with calamine.

53. Rhodocrosite.

Pretty rhombohedral crystals of this mineral, about 1 cm. in diameter, are found in the silver mines of PONSHIKARIBETS in Shiribeshi Province. Flattened forms of rhombohedra as well as peculiar saddle-shaped specimens are found in the KURATANI mines.

54. Siderite.

Good crystals of siderite are found in the Ōmori mines in IWAMI Province, while saddle-shaped small individuals of it are collected at the Uchinokuchi mines in Bungo Province.

Siderite in the form of dark brownish-grey cylindrical bodies is found in the gravel deposit of SHIBUYA near Tōkyō, and was described by Ogawa as a pseudomorph of decayed plant-roots.

55. Aragonite.

TAIRA in Shinano Province.—On a tributary of the upper part of the river Takasegawa flowing through the village of Taira, there are numerous small pits from which hot sulphurous water issues. On the sides of these solfataras, there are remains of huge sinter-cones still preserving central and secondary openings of former hot springs. In some of the now active pits of sulphurous water, are sometimes collected beautiful white-coloured small balls and irregular lumps of aragonite. These balls are also found in the shape of aggregates on parts of old sinter cones, where they usually have dirty-grey colour.

A complete series of transition could be traced from nearly perfect spheres to curious dodecahedral grains of the aragonite, through such spheres as are supplied with one or more depres-

sions. These dodecahedra resemble $\left[\frac{\infty 02}{2}\right]$ of the regular system and have rounded edges and slightly depressed faces. How such a remarkable form was produced is still a question.

The structure of each ball is concentric and radial-fibrous, with a nucleus of some decomposed rock-fragment. The size varies from that of very minute sand-grain up to that of a hen's egg (about 4 cm. in length).

MUTSUREJIMA near Nagasaki.—Kō has mentioned the occurrence of white and grey-yellow hemispherical aggregates of aragonite on a dark rock of this island.

The same author has also described the same mineral as being found in the ICHINOKAWA mines in Iyo.

56. Witherite.

Kō has mentioned radial aggregates of white-coloured witherite in metallic veins at TSUBAKI in Ugo, where crystals are also found with ∞P , $2P\infty$, ${}_6P$ and P .

57. Cerussite.

Kō has described stellar trillings of this mineral from the mines of KAMIOKA and KOSAKA (in Rikuchū). In the former locality P , ∞P , $P\infty$ and $\infty P\infty$ were observed. Saitō has brought from Kosaka, trillings showing a combination of P , $\infty P\infty$, ∞P , $P\infty$; and from ARAKAWA in Ugo, small pyramidal crystals of white cerussite. They are about 1.5 cm. in length and apparently in the form of hexagonal pyramids, which are all trillings with faces P and $\infty P\infty$. Besides, columnar aggregates of the same mineral occur in this locality.

58. Malachite.

In the mines of ANI and ARAKAWA, there occur, besides

the usual botryoidal aggregates, short minute needles of malachite, which sometimes show the ordinary crystalline habit under the microscope.

59. Azurite.

Small crystals of this mineral are found in the KOSAKA (Rikuchū) and ARAKAWA mines. They are less than 1.5 cm. in length. They must not be confused with barite plates coloured deep-blue with azurite substance, which are found in the same localities.

60. Psilomelane.

Manganese oxides (pyrolusite and psilomelane) of NUMADATE in Ugo, NISEUMBETS in Shiribeshi Province, &c., are mostly botryoidal, but sometimes also in more or less fibrous groups. Nasa has given a list of these oxides in different provinces of Japan.

F. Sulphates, Molybdates, &c.

61. Barite.

KURATANI in Kaga.—There are found in these mines white rhombic plates of barite with $\circ P$, ∞P , $P\bar{\infty}$, $\frac{1}{2}P\bar{\infty}$, &c. They enclose minute particles of jamesonite, in such distribution as to produce a zonal structure. The largest diameter of the crystals sometimes measures 9 cm.

NAKAYAMATŌGE and AIKAWA in Sado.—Besides nodules of radial-fibrous structure, there are found prismatic as well as rectangular-platy crystals, sometimes 8 cm. in length. Yamada has observed $\infty P\bar{\infty}$, $\infty P\infty$, $\circ P$, ∞P , $\infty P\bar{\infty}$, $P\bar{\infty}$, $\frac{1}{2}P\bar{\infty}$, $\frac{1}{4}P\bar{\infty}$, $P\infty$,

$P\bar{z}$, &c. The colour is brownish to bluish or quite colourless. A beautiful tabular crystal of colourless barite from Aikawa, (Watanabe's collection) measuring about 6 cm. in length and showing the combination ${}^0P. \infty P. \infty P\infty. P\infty. P\bar{\infty}. \frac{1}{2}P\bar{\infty}$, is marked on 0P with fine striations parallel to the a and b axis, as well as to the edges of combination of 0P with ∞P .

KOSAKA in Rikuchū.—Small tabular colourless crystals, (${}^0P. P\bar{\infty}. \frac{1}{2}P\bar{\infty}. \infty P\bar{\infty}. P\infty. \frac{1}{2}P\infty. \infty P\infty$) are here found in metallic veins.

Besides, we find, according to Kō, good crystals of barite from TSUBAKI, DAIRA and YATSUMORI in Ugo, KARUIZAWA in Fukushima-ken and PONSHIKARIBETS in Shiribeshi Province.

Pseudomorphs of the AIKAWA and ARAKAWA mines.—The curious quartz aggregates of the former locality, occurring in the shape of thick rhombic tables with rounded edges, are found to be probably a pseudomorph.

Those of the Arakawa mines are of five different habits. The first kind is in the form of nearly rhombic tubes with drusy quartz on their inner as well as outer walls. These are most probably quartz-envelopes, on prismatic barite crystals, which were dissolved away afterwards. The quartz individuals on the surface are of course later accretions. The second kind of the pseudomorph is a compact quartz-mass with cavities left after the dissolution of barite crystals. Its walls are casts of prismatic faces of two different indices, and show minute striations. The bottom is perpendicular to these walls. While the tubular pseudomorphs sometimes measure 18 cm. in length, the above mentioned cavities are much smaller in dimension. The third kind is represented by casts of rhombic tables of barite.

The fourth kind in the form of numerous smaller rhombic plates laid one over the other. The fifth is that of separate rhombic tables. The two last kinds are peculiarly hollow inside in many cases.

62. Anglesite.

Small white crystals, with brown coating, about $\frac{1}{2}$ cm. in length and showing mostly $P\infty$ and ∞P only, were found in the KOSAKA mines in Rikuchū.

63. Wulfenite.

Kō mentions small beautiful, orange-red crystals, of this mineral with ∞P , ∞P and $\frac{1}{16}P(?)$, from the SENNŌ mines in Echizen Province.

64. Scheelite.

Wada possesses a large yellowish-grey crystal of scheelite from SANNOTAKE in Buzen, with faces of $P\infty$ and P and nearly 5 cm. in length. This specimen is covered with a black coating.

In the province KAI, there are sometimes found brownish-coloured imperfect crystals and crystal fragments of the same mineral. One of the largest specimens measures about 4 cm. in diameter.

65. Wolframite.

Massive wolframite occurs in the TANIYAMA tin-mines in Satsuma Province, while crystals, sometimes 4 cm. long, were found in the tin placers of Takayama, &c. in Mino. The specimen from the latter locality, belonging to Wada, shows ∞P , $\infty P\infty$, $P(?)$ and $P\infty(?)$.

66. Linarite.

Ogawa has ascertained the presence of this mineral in nearly compact aggregates in the KAMIOKA mines in Hida.

67. Gypsum.

YOGOSAWA in Kai Province.—Good crystals with ∞P , $\infty P \bar{\infty}$, and $-P$, developed on all sides and sometimes measuring 3 cm. in length, are here collected. Besides simple crystals, there are also to be found twins on either $\infty P \bar{\infty}$ or $-P \bar{\infty}$.

According to Kō, good crystals are also found at MIYAZAKI in Iwate-ken; they occur, besides, at KUWABARA in Shinano Province, in OGASAWARAJIMA, at KWANKAIJI in Bungo, at KOSAKA in Rikuchū, &c. A beautiful fibrous aggregate of white gypsum has been found at YUDA in Rikuchū.

68. Melantherite.

OSARUZAWA in Rikuchū gives beautiful crystals and fibrous aggregates of this mineral, in association with copper ore. The crystals are flattened on $\infty P \bar{\infty}$ and elongated in the direction of the c axis. The length attains 2.5 cm. There are observed $\infty P \bar{\infty}$, ∞P , ${}_6P$, $P \bar{\infty}$, $-\frac{1}{3}P \bar{\infty}$, $\frac{2}{3}P \bar{\infty}$, &c. The colour of crystals is greenish-blue, with a yellow tinge on the edges, which is due to oxidation. The aggregate shows a silky lustre, and resembles fine asbestos in white-coloured long fibres. The crystals contain some copper, while the aggregates, which are said to be derived from the decomposed crystals, are quite free from it.

69. Alunite.

At TOCHIHARA in Harima, there has been found a compact specimen of this mineral, which Kochibe believes to be derived

No specimens of Reinite (See Neues Jahrbuch für Mineralogie &c., 1879.) were found in collections accessible to me.

from decomposed liparite. The specimen was analyzed in the laboratory of the Imperial Geological Survey.

G. Aluminates, Ferrates, &c.

70. Chromite.

Small octahedral crystals and aggregates are found, together with kämmererite, in the serpentine of WASHIDANI, &c., in Bungo. In the MUKAWA river in Iburi Province, Ishikawa observed another case of the occurrence of this mineral in common serpentine.

71. Magnetite.

Dodecahedral crystals of this mineral about 2 cm. in diameter are found as druses in the magnetite aggregate found with garnet rock at ŌHASHI, &c., near Kamaishi in Rikuchū. Minute octahedra of magnetite are enclosed in the chlorite schist of NOGAMI in Musashi, SONOKIGŌRI in Hizen, &c. Minute crystals in ∞ O are found in the massive magnetite of KURODAKE in Etchū, associated with rock crystal, &c., in a garnet rock. The magnetite of NAKAKOSAKA in Kōzuke Province is fine granular, and found as huge masses in a pale-coloured dioritic rock. Yamashita and Ōtsuka have studied the magnetic iron sand in the western part of HONSHŪ, &c.

72. Chrysoberyl.

A minute trilling of chrysoberyl, said to have been found at TAKAYAMA in Mino, is found in the collection of the Imperial Geological Survey.

H. Phosphates, Arseniates, Niobates, &c.

73. Fergusonite.

Irregular columnar individuals of fergusonite with fibrous surface occur in the tin placers of TAKAYAMA. According to Takimoto, there are occasionally found crystals about 0.7 cm. in length, terminating in pyramids.

74. Monazite.

Red-brown crystals, more than 0.5 cm. in diameter, with curved faces, and found enclosed in the topaz crystals from TANOKAMIYAMA in Ōmi, were determined by Ogawa as monazite after a qualitative analysis made by a chemist of the Geological Survey.

75. Apatite.

Good crystals of this mineral are very rare in Japan. We find, in old collections, a few yellowish crystals from Miyamoto (?) in Kai Province with $\circ P$, ∞P , ∞P_2 , &c. Their rough faces are covered with a white powder. The specimens are sometimes 8 cm. in diameter; there are partings parallel to $\circ P$ and ∞P .

A semi-transparent glassy crystal, about 5 cm. in diameter of basal sections, and showing $\circ P$, ∞P , ∞P_2 , $\frac{3}{2}P$, $\frac{3}{4}P$, and mP_2 , is found in Wada's collection and is said to have come from MIYAMOTO. This specimen, which differs from the above only in having smooth shining faces, is the best specimen of macroscopic apatite crystals thus far discovered in Japan!

Massive apatite with clayey and sandy admixtures, found in the shale on the coast of HYŪGA Province, has been treated in detail by Ōtsuka and Tsunetō from geological and agronomical points of view.

76. Pyromorphite.

Minute crystals (∞P , $\circ P$) of green pyromorphite are found in the metallic veins of MOZUMI in Hida, ARAKAWA in Ugo, and KOSAKA in Rikuchū.

77. Adamine (?).

Wada possesses a specimen of adamine (?) forming crystals on a brown ferruginous mass. It is said to have been sent from KIURA in Bungo.

78. Olivenite (?).

A specimen in Wada's collection, in the form of minute prismatic crystals, said to have been found in Settsu Province.

79. Vivianite.

From KODAKI in the Ashio mining district in Shimotsuke Province, there were once obtained in one of the veins, many perfect crystals of vivianite, which were nearly colourless, with only a slight blue tinge. They are 1.5 cm. in maximum length. Hiki has distinguished in them, the faces of $\infty P \infty$, ∞P , $\infty P \infty$, P and $P \infty$.

Earthy vivianite forms fossils of plant leaves in the grey tuff of KIMPŌZAN in Higo Province, and irregular patches in a similar tuff of OGASHIMA in Ugo.

80. Erythrine.

This mineral is found only in the form of thin encrustations on the silver ores of KANAGASE in Tajima, which contain argentite, fahlore, native bismuth, &c.

81. Scorodite (?).

At INUNAGARE in the mining district of Kiura in Bungo, dark-green octahedral crystals with curved faces have been collected. The diameter of the crystals is about 0.3 cm. Sasamoto, Yamada, &c., who first mentioned the occurrence of this mineral at Inunagare, made its qualitative analysis; but the faces have not yet been fully determined. Yamada has found the same mineral also at DATSUGATAO in Kiura.

I. Silicates, Titanates, &c.**82. Staurolite.**

According to Kochibe, etc., this mineral occurs at KUSHIGI in Hizen.

83. Hemimorphite.

Wada possesses a beautiful druse of colourless hemimorphite, said to have been found at KURANARI in Bungo.

84. Andalusite.

Microscopic individuals showing distinct pleochroism were found in the mica-clay slate of NIYAMAHAMA in Rikuzen Province. KIKUCHI has found similar specimens at MATSUDA, &c., in

Shimotsuke, also at a place near Tsukuba in Hitachi, &c. Pebbles of biotite-schist from the TOYOGAWA river and from CHIKURAZAWA in Mikawa contain small decomposed andalusite crystals, like those observed by Kotō, &c., near Kankyozan in Hitachi and other places.

According to Kikuchi and Nishiwada, chiastolite crystals in clay-slate, with a sectional diameter measuring about 0.2 cm., are found at Usuginu in Rikuchū.

85. Sillimanite.

Only found as microscopic aggregates in the mica schist near TSUKUBA in Hitachi, and also in the shape of eyes in the biotite schist of Okunoin on HONGŪZAN in Mikawa.

86. Cyanite.

Sasamoto, &c. found cyanite without terminal faces, at the contact of crystalline schist with diorite at ŌGUSHI in Hizen.

87. Topaz.

The two principal localities of topaz in Japan are TAKAYAMA, &c., in Mino, and TANOKAMIYAMA in Ōmi. Hiki (Journal of the Science College of the Imperial University of Tōkyō, 1895) has described the crystal form and other characters of the Mino crystals and the etching figures of those of Mino and Ōmi. Kō has given general characters of the Ōmi specimens. Those from Mino are often rounded by rolling, but those of Ōmi are less deformed. The difference is probably due to the greater length of the river course, along which the Mino crystals were rolled downwards by water.

MINO.—The larger crystals from Takayama, &c., have mostly domatic, but sometimes basal or pyramidal, terminations.

The colour of topaz from Mino are bluish or brownish to quite colourless. Pleochroism is sometimes distinct.

As in the crystals from Tanokamiyama, we often find a peculiar division of individuals into differently coloured sections, being light brownish on the ends of the a axis and light bluish on those of the b axis. The topaz crystals from Mino are from 0.2 cm. to 12.5 cm. in the longer diameter of basal sections. Enclosures in this mineral consist of tourmaline, cassiterite, chlorite (?), liquid, gas, &c. Crystal faces usually observed are: ${}_0P$, ${}_2P\infty$, ${}_4P\infty$, ${}_2P\bar{\infty}$, P , ${}_2P$, ∞P , and $\infty P\bar{2}$. Besides these, are less frequently observed: $\infty P\bar{3}$, $\infty P\bar{2}$, $\infty P\bar{2}$, $\infty P\bar{4}$, $\infty P\bar{5}$, $\infty P\bar{3}$, $\infty P\infty$, $\frac{4}{3}P\infty$, $\frac{2}{3}P$, $\frac{2}{3}P\bar{\infty}$, ${}_4P\bar{2}$, ${}_2P\bar{2}$, $\frac{4}{3}P\bar{2}$, $\frac{6}{5}P\bar{3}$, $\frac{6}{5}P$, $\frac{4}{5}P$, &c. The last mentioned three faces were found by Redlich ('Tschermak's Mittheilungen 1897).

The following natural etching figures of Mino crystals are mentioned in Hiki's work:—

On ${}_0P$ (c), numerous rectangular pyramids.

On ${}_2P\infty$ (f), triangular eminences, with their base parallel to the a axis, with apex directed towards the adjacent face of ${}_0P$, and with two other sides parallel to the edges of combination of $\infty P\bar{2}$ and ${}_2P\infty$.

On ${}_2P$ (o), triangular and other eminences.

On P , (u), irregular horizontal striæ.

On ∞P (m), quadrilateral eminences.

Besides there are less important figures on various faces.

In the beautiful topaz collection of Wada, which is specially rich in crystal forms, enclosures, etching figures, &c. of the Japanese specimens there are to be seen many other characteristic etching figures. For instance, in one nearly colourless crystal from Mino measuring about 2 cm. along the b axis, there are

on $\circ P$, very deep depressions with curvilinear, six or eight-sided pits elongated parallel to the b axis. The same crystal is etched on the face f with oblong hillocks, pointed downwards. This specimen is, moreover, etched on other faces and edges.

Another crystal from Mino, with a brownish colour at the ends of a axis and a bluish along b , is etched on the face f with oblong depressions which are broader on the upper end and sharp-pointed on the lower. The faces u and o carry irregular nearly horizontal grooves. The d is similarly grooved vertically, and c is roughened with small pyramidal elevations.

The above mentioned parallel depressions on f are sometimes deep and elongated by their union, thus causing a striated appearance of the face.

One large crystal from Mino is strongly corroded and show numerous projecting pyramidal eminences on the quite irregular upper and lower faces of the individual. This specimen shows the peculiar colouration mentioned in p. 249.

The chagration of the basal face of a brown crystal from Ōmi, which is without lustre on this particular face, represents in miniature the above mentioned pyramids. That these are due to etching action and not to the arrangement of sub-individuals, is shown by some specimens in which the etching figures on f , u , &c., are in some way connected with the depressions between the pyramidal prominences, which are quite frequently observed on the topaz from Ōmi.

Takimoto has prepared numerous cleavage pieces of the smaller Mino crystals (below 1 cm. in sectional diameter) and found beautiful and complicated optical anomalies, which

slightly differ from those of Brazilian crystals in Brauns' *Optischen Anomalien*, 1890.

ŌMI.—Kō has described topaz of Tanokamiyama in Ōmi, which attains as large a size as that from Mino. Small individuals less than 1 cm. in diameter of the basal section are very rarely found, in contrast to their abundance in Mino. The crystalline habit is usually short columnar, while long columnar forms, often found in Mino, are exceedingly seldom observed. The colour is mostly brownish. Colourless, bluish and greenish crystals are less frequent; the beautiful light-green colour seen in a specimen of Mino topaz in Wada's collection is found in none from Ōmi. The following faces have been recognised:—

${}_1P$, P , ${}_2P$, ∞P , ∞P_2 , ${}_2P\infty$, ${}_4P\infty$, ${}_2P\infty$; besides, ${}_3P$, ${}_2P_2$, ∞P_2 , ∞P_3 , ∞P_4 , $\infty P\infty$, ${}_3P\infty$, ${}_3P\infty$.

Most of the crystals are domatic in termination, but sometimes we find pyramidal or basal endings.

Enclosures in the Topaz of Ōmi are tourmaline, beryl (?) and monazite. The last mineral is found in red-brown crystals with curved faces. The etching figures are essentially like those of Mino specimens; only the deep octagonal and hexagonal pits on c of the latter have not been found.

A peculiar paragenetic connection of the Ōmi topaz with a flesh-red coloured potash-felspar is known to collectors. Wada recognises the existence of two generations in the Ōmi topaz. The younger individuals are smaller in size, usually developed at both ends and richer in faces, than the older generation. They lie on feldspars instead of making intergrowth with these.

Analysis of Ōmi topaz by Takayama, chemist to the Imperial Geological Survey:

	I	II
Si O ₂	31.30	31.95
Al ₂ O ₃	56.72	56.59
F	18.36	18.01
	<hr/> 106.38	<hr/> 106.55

88. Tourmaline.

Black crystals, usually with only R, $-2R$, ∞P , ∞P_2 &c., are found (generally not in abundance) in the pegmatite of YAMANŌO, SAIMARU, OGANETA, &c., in Hitachi Province. A pseudomorph of mica after tourmaline occurs at YOKOGAWA, &c., in the same province and measures about 2 cm. in diameter of basal sections.

Peculiar flat crystals of black tourmaline, with R prevailing and ∞P much shortened, occur at GOSHODAIRA in Shinano Province. Their diameter is about 5 cm.

Beautiful radial aggregates of dark needle-shaped tourmaline occur with quartz-vein in pegmatite in an old tin-mine of SENSUI in Obira, Bungo Province. Some of the needles have rhombohedral terminations; many of them are very thin, brown-coloured, and appear as fine enclosures in quartz crystals as well as tufts of hairs on their outside.

Some crystals of tourmaline also occur, according to Kochibe and others, at KUSHIGI in Hizen Province, &c.

89. Lievrite.

Crystals of this mineral are known to occur at KAMIOKA in Hida, (according to Kō). Those of GINJIKI in Obira, Bungo Province, are found in abundance, together with grey sharp-edged

brown garnet, &c. Wada possesses a good specimen of the lievrite with crystals about 0.7 cm. broad and showing ∞P , $\infty P\bar{z}$, P and $P\bar{\omega}$.

Massive aggregates of lievrite form vein-stuff in the copper mine of ZŌMEKI near Bakwan.

90. Epidote.

In the magnetite deposits near KAMAISHI in Rikuchū Province, green to dark-green epidote crystals are found. A good crystal in Wada's collection, about 1 cm. broad, shows ∞P , $P\bar{\omega}$, $P\bar{\delta}$ and $\infty P\bar{\omega}$, besides other small faces.

At TAKESHI in Shinano, pretty druses of green epidote needles are found in a decomposed porphyrite-tuff. The geode is irregularly ellipsoidal, and is easily hammered out from the rock containing it. The combination shown by the crystals seem to be $P\bar{\omega}$, $\infty P\bar{\omega}$, P , ∞P .

91. Piedmonite.

This mineral is abundantly found as a microscopic ingredient of the piedmonite schist of SHIKOKU, KWANTŌ, &c. (see Kotō's description, in the Journal of the Science College of the Imperial University of Tōkyō, 1887). Reddish aggregates of piedmontite are found in a rhyolite near the town of UEDA in Shinano, and were described by Yamasaki in the same journal, 1898.

92. Orthite.

According to Ishiwara, Ogawa &c., this mineral is found in the granite of AWAJI Province, in that near MIDERA in Ōmi Province, in the biotite-schist of the neighbourhood of TAHITO in

the Abukuma hills, and in a gneiss of the lower course of the TENRIU river.

93. Vesuvianite.

Kikuchi has described crystals of dark brownish-green vesuvianite from INUNAGARE in Kiura in Bungo Province, occurring in a crystalline limestone together with dark-green and brown garnets. The largest crystals are about 3 cm. in width. Zonal structures are quite common, with optically different characters in different zones. Kikuchi has distinguished $\circ P$, ∞P , $\infty P \infty$, $P \infty$, P , $\frac{1}{3}P$, $\frac{1}{2}P$, $\frac{2}{3}P_3$ and ∞P_2 , besides which I have found $\frac{1}{3}P \infty$, &c.

94. Olivine.

Ishii has mentioned the occurrence of brown crystals of olivine in the basaltic rock of NISHINOTAKE in Hizen, where good crystals of dark-green augite are collected. The olivine is about 0.5 cm. in diameter and shows different habits of crystals by the prevalence of different faces. There are found $P \infty$, $4P \infty$, $\infty P \infty$, $\infty P \infty$, $\infty P \infty$, $\infty P \infty$, &c. Analysis by Kondō gave

Si O ₂	38.74
Mg O	43.53
Fe O	16.60
Ca O	trace.
	<hr/> 98.87

95. Danburite.

At HIGASHISHŌDŌ in Obira, Bungo Province, are found

among the detritus of a valley, aggregates of danburite and its beautiful crystals. The largest is 1 cm. broad. Yellow garnet is associated with this mineral. Observed crystal faces are $\infty P\bar{\infty}$, $\infty P\infty$, ${}_0P \infty P$, $\infty P\bar{2}$, $\infty P\bar{4}$, $P\bar{\infty}$, ${}_4P\infty$, ${}_2P\bar{4}$ and ${}_2P\bar{2}$ (?). On the face ${}_4P\infty$, are horizontal striations and nearly rectangular depressions elongated parallel to the a axis. The edges of combination of $P\bar{\infty}$ and ${}_2P\bar{4}$ are usually rounded, while those of ${}_0P$ with other faces are sometimes similarly modified.

96. Garnet.

None of the Japanese garnets has been carefully analyzed, and we have only to classify them, for the present, according to their colour and mode of occurrence.

The garnet rocks on the west of KAMAISHI in Rikuchū, and on KURODAKE in Etchū, which contain magnetite, are very interesting. They are found at the contact of palæozoic rocks with granitic and dioritic masses, and in them at both localities good garnet crystals are often collected. At WADATŌGE in Shinano, cavities in a white glassy rock connected with spherulitic obsidian contain dark-red garnet crystals sitting on their walls. At YAMANO in Hitachi, pegmatite contains numerous brownish-red garnet together with silvery and dark-coloured mica scales. At HOGI in Nagato Province, garnet is found in crystalline limestone. Other occurrences of various garnets in the same rock are those at KAWAHAKE and TOKIWA in Shinano Province and other places.

ŌHASHI, &c., on the west of Kamaishi.—Green or dark-green crystals of garnet on magnetite are not seldom observed. Large dark-red crystals in ${}_2O_2$ with subordinate ${}_mO_n$, found in Wada's collection, measure about 3.5 cm. in diameter. These

separate crystals have not yet been optically studied; but each garnet grain in a microscopic slide of the brown garnet rock is finely zonal in structure, very distinctly double-refracting, and shows division into sectors.

KURODAKE in Etchū.—In the garnet rocks of yellow to red-brown colour, are found various garnet crystals either forming druses in the rock or imbedded in quartz veins running through it. Optical anomalies of the dodecahedral type are easily observed in many of them. We can distinguish in this locality the following varieties of garnet :

- (1.) Dark-brown crystals attaining 2 cm. in diameter, forming aggregates and druses in the garnet rock.
- (2.) Reddish-brown smaller crystals.
- (3.) Yellow-coloured minute crystals (rare).
- (4.) Dirty brownish-black crystals (rare).
- (5.) Brownish-black crystals, always imbedded in quartz.

Nos. 1-3 are found with dodecahedral as well as icositetrahedral habit, while No. 4 is in icositetrahedra with small faces of ∞O_2 . Another ∞O_n was found in the dodecahedral crystals of No. 2. No. 5 is always dodecahedral. Sometimes we find No. 1 with a brownish-yellow zone outside.

WADATŌGE in Shinano.—The dark-red, brilliant garnet crystals are almost black in external appearance, with prevailing ∞O and smaller faces of $2O_2$, and are less than 2 cm. in diameter.

YAMANŌO in Hitachi.—The brownish-red, much cracked garnet of this locality is in $2O_2$ with subordinate ∞O , and is covered with striations parallel to the edges of combination of these two forms. A simple form of ∞O is seldom observed. Similar garnet crystals are also found in the pegmatite

of KUMINATSU near Tsukuba in Hitachi. The diameter of these garnets is below 1 cm. Small faces of mO_n are sometimes met with on them.

HOGI in Nagato.—Greenish-yellow to dark-green crystals of garnet, usually in ∞O , ${}_2O_2$, but sometimes in ∞O only, are found there rarely attaining 6 cm. in diameter. Fine zonal structures, and division into sectors are easily observed. Kō has found a small quantity of wollastonite together with the garnet.

AT TOKIWA in Shinano, brownish-yellow dodecahedral crystals of garnet, essentially resembling those of Hogi, are found with wollastonite, fine-granular green augite aggregates, brown-red garnet masses, &c. These minerals are so abundant that the crystalline limestone containing them does not yield white lime.

Various garnets occur at different places in OBIRA in Bungo. Thus, we have: yellow-coloured small crystals associated with danburite at Higashishōdō; brown garnet, often with yellow zone outside, in the crystalline limestone of the same place; dark-green garnet in the hedenbergite mass of Ōkuradani; brown crystals with lievrite, grey axinite, &c. at Ginjiki; and so forth.

The dark-green garnet in the crystalline limestone of KAWAHAKE in Shinano, where an augite resembling hedenbergite and a pseudomorph of talc after tremolite are found, is nearly similar to the same-coloured garnet of INUNAGARE in Obira found in crystalline limestone.

Dark-brown dirty-looking crystals of garnet in ${}_2O_2$ found near TAKATŌ in Shinano, occur in biotite-gneiss; while clear brownish-coloured garnet crystals (${}_2O_2$) of YASUSADA in Mikawa Province are associated with rhodonite in a quartz vein in biotite-gneiss.

A large quantity of brown-red garnet, in the form of separate crystals and sand, taken from KONGŌSAN in Kawachi Province, is used as polishing material in Tōkyō.

97. Chrysocolla.

This mineral is found in several Japanese copper mines, but a specially interesting specimen is from HISAN-ICHI near Arakawa in Ugo. On the surface of its amorphous mass, are found numerous small chrysocolla pseudomorphs with curved faces, looking like a rhombic crystal in $P\infty$. ∞P . $\infty P\infty$; angles on the upper edge of the dome and the front edge of the prism measure about 140° . The pseudomorph is about 0.4 cm. wide.

98. Axinite.

Two essentially different varieties of axinite are found in OBIRA in Bungo.

Kikuchi has described dark-brown to dark-violet crystals from ŌKURADANI in Obira. They form druses and aggregates of individuals, attaining a length of 2 cm. and characterized by the combination of following faces:—

$\infty P\infty$, $\infty P\infty$, ${}_0P$, ∞P , $\infty P'$, P' , $'P$, $\frac{1}{2}P$, ${}_2P'$, $\infty P\infty$, ${}_3P\infty$, ${}_5P\infty$, besides, ${}_2P'\infty$ and ${}_2P\infty$, which are but rarely observed.

This variety is not sharp-edged nor thin tabular in habit; but rather prismatic with striations on the broad face of P and on various prismatic faces. Kajiura's analysis gave the following result:

Si O ₂	41.87
Al ₂ O ₃	19.25
Fe ₂ O ₃	11.79
Ca O	17.75
Mn ₂ O ₃	5.62
B ₂ O ₃	1.59
Na ₂ O	1.79
H ₂ O	0.87
K ₂ O	trace
Mg O	trace
	<hr/> 100.53

As minerals occurring in paragenesis with this axinite, we have hedenbergite and its decomposition product, dark-green garnet, magnetic pyrite, arsenopyrite, fluorite, &c.

At GINJIKI in Obira as well as near this place, we find another kind of axinite, which is grey, sharp edged, glassy in appearance, and with striations on prismatic faces. In a dark-green hornblende aggregate associated with this axinite, there was found a vein of argentiferous galena. Brown garnet, lievrite, &c. are found with this variety of axinite.

99. Biotite (?).

A well-known locality of the various kinds of mica is TANOKAMIYAMA in Ōmi, which I will take as the starting point of my investigation of Japanese micas. The biotite of this place is found in dark-green six-sided or irregular plates, with foldings parallel to the lines of pressure-figure. The diameter of the plates attains 5 cm. The crystal faces are not measurable, for the lamellae composing each crystal are not

quite parallel to one-another ; numerous oblique faces on the lateral sides are therefore of no definite direction. This mica is nearly uniaxial. Analysis by Kodera gave

Si O ₂	35.87
Al ₂ O ₃	22.69
Fe ₂ O ₃	20.90
Mn O	5.65
K ₂ O	6.70
Na ₂ O	2.52
Mg O	0.32
Ti O ₂	0.35
H ₂ O	1.00
F	3.19
	<hr/> 99.19

100. Zinnwaldite (?), Muscovite (?), &c.

TANOKAMIYAMA in Ōmi.—In the pegmatite of this place there are found, together with the above mentioned biotite, various light-coloured micas as follows :

a.) Reddish-brown, light brownish-grey to nearly colourless plates, sometimes 15 cm. in diameter. On cleavage surface, there are numerous foldings parallel to the lines of pressure-figure. Fukuchi has distinguished with a contact goniometer, ∞P , $^{\circ}P$, $\infty P \infty$, $-\frac{2}{3}P \frac{2}{3}$, $-\frac{1}{4}P$, $\infty P \infty$, &c. He regards the many re-entrant angles on the sides as casts of other minerals found in intergrowth. A parting parallel to P is sometimes observed. Twins are quite numerous. The optical plane is parallel to the symmetry plane ; the angle of optical axes is large. With a blowpipe, one can distinctly observe the flame-colour of intense red ; but an analysis by Kodera is as follows :

Si O ₂	46.13
Al ₂ O ₃	17.03
Fe ₂ O ₃	4.64
Mn O	6.27
K ₂ O	10.09
Na ₂ O	4.12
Mg O	0.43
Ti O ₂	2.77
H ₂ O	2.31
F	6.89
	<hr/> 100.68

This mica is most likely zinnwaldite.

b.) Small silver-white six-sided plates attached to the crystals of potash-felspar. Their diameter is about 1.5 cm. or less. The cleavage-surface is much folded parallel to the lines of pressure-figure. Twinning is sometimes observed. The optical plane is parallel to a line of the pressure figure. The angle of optical axes is large. This variety sometimes overlaps a similarly oriented six-sided biotite plate, so as to form a broad outer zone to it. This mica is probably muscovite.

c.) Minute six-sided plates like (b), but less than 0.8 cm. in diameter and with curved cleavage-lamellæ. They often show, in crossed nicols, a subdivision into six triangular fields and a zonal structure with zones of different orientations.

d.) Brownish-grey six-sided or irregular plates with small angles of optical axes. This variety is sometimes 5 cm. in diameter. It is altered, along cleavage as well as on the surface, into a scaly silver-white mica, with a large angle of optical axes and sometimes forming druses of small tabular crystals.

e.) Purplish-white mica (rare), with a large optical angle and the optical plane parallel to the symmetry plane.

Fukuchi has found, that the muscovite (b) shows a transition into the dark-green biotite, either directly or through intermediate stage of alteration represented by the zinnwaldite (a). The biotite is surrounded sometimes by the zinnwaldite and sometimes by the muscovite, their boundaries against the enclosed biotite being often very distinct.

ODAYAMA near Mt. Tsukuba in Hitachi.—In the granite of this place are found small plates of white mica with a brownish grey tinge. It resembles the zinnwaldite of Tanokamiyama.

Various mica specimens of white, brown, green, and other colours are found at several other localities in Japan. A dirty dark-brown mica of KAI has been known from early times, by its elongating into a long columnar form, when put on charcoal fire. Its analysis by Hida is as follows :

Si O ₂	38.45
Al ₂ O ₃	15.53
Fe ₂ O ₃	22.73
Fe O	1.71
Ca O	2.22
Mg O	7.85
Na ₂ O	2.16
K ₂ O	2.25
H ₂ O	7.20
	<hr/> 100.10

101. Ottrelite.

This mineral was found in microscopic individuals in a slide of the hornfels from the HIDAKA mountain-range in Hok-

kaidō (see Jimbō's "Geological sketch," 1892) ; also in a chlorite schist of SUKEGAWA in Hitachi.

102. Serpentine.

Various kinds of peridotites, gabbros and serpentines are found in different parts of Japan (see Harada's *Japanische Inseln*, 1889). The ophicalcite of KANASAKI in Musashi and the serpentinized peridotite of MACHIYA in Hitachi are very beautiful when polished. The latter shows black-coloured patches on a white ground. The black colour is due to chromite grains secreted out, while the white part consists of serpentinous and other secondary substances.

Asbestos of economic interest is found in the serpentines of several places, the most important of which are in the provinces of HIZEN and HIGO. Nasa has given the principal localities of Japanese asbestos.

103. Talc.

Greenish-white irregular plates of talc are found at ŌGUSHI in Hizen ; a pseudomorph after tremolite is found in the crystalline limestone of KAWAHAKE in Shinano.

104. Agalmatolite.

At MITSUISHI in Bizen Province, agalmatolite, connected with liparite and believed by Kochibe, &c. to be an alteration product from its tuff, is found in the form of grey, white, yellowish or brownish masses.

105. Nepheline.

Ogawa has observed this mineral as a microscopic ingredi-

ent of a dyke rock in the palæozoic region of HOTSUMURA in Tamba Province.

106. Cordierite.

WATARASEGAWA in Shimotsuke Province.—A detailed description of a cordierite trilling of white colour and very weak pleochroism, was given by Kikuchi in the Journal of the Science College of the Imperial University of Tōkyō, 1889. In this locality the cordierite is found only in hexagonal columns, which are trillings with a distinct zonal structure and peculiarly distributed coaly substance. The crystals are about 0.5 cm. in diameter of cross sections and are found in clayslate altered by granite contact. An analysis by Shimizu is mentioned by Kikuchi.

Similar specimens of very minute size are found in the mica clayslate of SEKINOTSU in Ōmi and of many other places, which are mentioned by Jimbō in the Geological Sketch of Hokkaidō and by KIKUCHI in his paper on cordierite. KAMEOKA in Tamba is a locality of green pinite after cordierite trilling, TORIHAMA in Wakasa that of a pale micaceous substance in the same form. Specimens from these two places are about 1 cm. in diameter of basal section.

Hussak has given a description of a blue-coloured, strongly pleochroic, cordierite aggregates found in white porcelain-like fragments. His specimens are from ASAMA volcano in Shinano, while similar fragments were found by Yamasaki on the volcano of GANJUSAN in Rikuchū and by Ogawa on that of NORIKURA in Shinano.

107. Bronzite.

Kikuchi has given an account of a green bronzite from

OGASAWARAJIMA in the Journal of the Science College of the Imperial University of Tōkyō, 1889. The mineral is found in a glass, in the shape of crystal skeletons and crystals, together with a similar-coloured monoclinic pyroxene in $\infty P \bar{\infty}$, ∞P , ${}_0P$, P . The length of the green bronzite is 0.5 to 1 cm.; it forms a parallel growth with the monoclinic pyroxene and has the crystal faces $\infty P \bar{\infty}$, $\infty P \infty$, ∞P , $P \bar{z}$ and ${}_2P \bar{z}$. An analysis by Shimizu is mentioned in Kikuchi's work.

108. Augite.

NISHINOTAKE in Hizen.—Ishii has described porphyritic individuals of a dark-green augite and a brown olivine found in the basalt and its agglomerate exposed at this locality. The augite crystals measure about 0.1 cm. to 2 cm. along the vertical axis and show usually the faces $\infty P \bar{\infty}$, $\infty P \infty$, ${}_0P$, ∞P and P and sometimes ${}_2P$ and ${}_2P \infty$ besides.

The crystalline habit is generally thick columnar, but we find also tabular forms with prevailing ${}_0P$. Twinning on $\infty P \bar{\infty}$ is quite frequent, and often repeated in the same individual. Pleochroism is weak, glass and other interpositions are numerous.

AZUNA near Yatsugatake in Kai, TATESHINA, &c. in Shinano, ONNADANI near Yoneyama in Echigo, and MYŌGI in Kōzuke.—The black augites from all these localities are similar in characters, and distinguished from other specimens by showing an apparently simple, rhombic-hemimorphic habit of penetration-twins on $\infty P \bar{\infty}$. Specimens from Azuna have been described by Ishiwara, those of Onnadani by Iwasaki, and and those of Tateshina, Myōgi &c. were studied by Takimoto.

The crystals from these different places will be treated together in the following lines :—

The size of the individuals varies in thickness from about 0.1 cm. to more than 0.7 cm., as in the large crystals from Onnadani. Observed crystal faces are $\infty P \nearrow$, $\infty P \overline{\searrow}$, ${}_0P$, ∞P , $P \overline{\searrow}$, P , ${}_2P$, &c. The face of $P \overline{\searrow}$ is usually hard to measure with the reflection goniometer. Simple individuals are rare, and ordinary twins on $\infty P \overline{\searrow}$ with a single re-entrant angle are not numerous. Most of the specimens are in the shape of simple looking penetration-twins with different faces on both poles. Sections parallel to $\infty P \nearrow$ show a characteristic subdivision into four sectors of twinning individuals. Polysynthetic twins on $\infty P \overline{\searrow}$ are not rare; when the thin wedge-shaped middle lamella of a trilling is very small in dimension, the clinopinacoidal section appears like that of a simple crystal. In such a case different arrangements of zonal enclosures in the two members of the twin can be relied upon for tracing the twinning suture. Hour-glass structure is often observed. Interpositions are very numerous.

The mother rocks of these black augites are either andesite or its agglomerate.

Kozōri in Sano in Kai Province.—Hirabayashi, Takimoto and others have collected green augite in a dark-green dyke-rock piercing sandstone. The largest individual attains a length of 4 cm. Observed faces are $\infty P \nearrow$, $\infty P \overline{\searrow}$, ${}_0P$, ∞P , P , $-P$, ${}_2P$, $-{}_2P$ and ${}_2P \nearrow$, among which ${}_2P$, $-{}_2P$ and ${}_2P \nearrow$ are small. The most frequent combinations are ∞P , $\infty P \overline{\searrow}$, $\infty P \nearrow$, P . Those with ${}_0P$ besides are not numerous, also the three last mentioned faces are often not found. Twins on $\infty P \overline{\searrow}$ are frequently observed. A collection of these augite crystals is easily made from

decomposed parts of the mother rock, as is the case with the black augite of Azuna and other localities.

109. Wollastonite.

ISHIYAMA and GOBESSHO in Ōmi, INARIYAMA in Yamashiro, ISHIGURE in Ise, TOKIWA in Shinano, a place near KASAMA in Hitachi and other places are localities of fine-fibrous to needle-shaped aggregates of wollastonite in crystalline limestone. Some of the specimens from the provinces of Ōmi and Mino have been analyzed. The wollastonite of Ishiyama is found along the stratification of limestone, those of Gobessho and Tokiwa some times form zones parallel to those of red garnet, of green augite, &c.

110. Hedenbergite.

At ŌKURADANI in Obira in Bungo Province, there is an extensive aggregate of hedenbergite in biotite-hornfels. Here the mineral is found in large crystals, sometimes 18 cm. in length, or in radial-columnar as well as granular aggregates. The large individuals are cemented together by fluorite. This hedenbergite rock contains numerous dark-green garnet crystals and is traversed by veins, in which assenopyrite, pyrrhotite, copper pyrite, &c., are found in massive state. The veins just mentioned were formerly worked for copper. In them dark-brown or dark-violet axinite crystals, as well as very good hedenbergite specimens (with P , ∞P , ∞P , ∞P , P , P , P , and $-\text{P}$) are collected in this. The following is one of the analyses made by the chemists of the Imperial Geological Survey :

Si O ₂	47.13
Fe O	24.46
Mn O	0.73
Ca O	23.23
Mg O	2.40
K ₂ O	0.13
Na ₂ O	0.98
H ₂ O	1.48
	<hr/> 100.54

At KAWAHAKE in Shinano, minute dark-green crystals and coarse crystalline aggregates of hedenbergite (?) are found in crystalline limestones.

At KURODAKE in Etchū, a brownish-grey fibrous aggregate of augite is partly oxidised to a brown-black submetallic substance. Larger individuals of this mineral are in prismatic crystals with cleavages.

111. Diallage.

Diallage is found in the gabbros and diallage-rocks of several places in Japan, the most beautiful specimens of large size being found at MINEOKA in Awa (Honshū) and at URITŌGE in Mikawa.

112. Rhodonite.

At YASUSADA in Mikawa, Ishikawa has found minute rhodonite crystals on masses of that mineral, found in a quartz vein through gneiss. Observed crystal faces are ∞P , $\infty P\infty$, $\infty'P$, $\infty P'$, ${}_2P$, ${}_2P$, P' , P .

At OKUSAKO in Kiura in Bungo Province, a rhodonite mass is found in biotite-hornfels.

Black oxides of manganese are associated with these rhodonite specimens.

113. Tremolite.

This mineral is found as fine-fibrous aggregates in the crystalline limestone of ISHIGURE in Ise, where wollastonite is found in a large quantity. At this place, the granite, which has altered the paleozoic rocks, contains fluorite veins.

A pseudomorph of white talc after tremolite was found by Hoshina in the crystalline limestone of KAWAHAKI in Shinano. The original form of the tremolite, as columnar aggregates with characteristic prismatic angles, is distinct.

114. Hornblende.

Loose black crystals, about 1 cm. long, of porphyritic hornblende, are found covered with grey and brown secondary substances on a road ascending to the mountain of HAKUSAN in Kaga. Crystal faces are ∞P , $\infty P \bar{\infty}$, $\circ P$ and P . Twins on $\infty P \bar{\infty}$ are numerous.

115. Glaucophane.

Blue-coloured glaucophane-schists and other rocks containing glaucophane, are found in different parts of Japan. (See Kotō's note on glaucophane, in the Journal of the Science College of the Imperial University of Tōkyō, 1887).

116 Beryl.

TAKAYAMA, &c. in Mino.—There are sometimes found light-bluish to nearly colourless crystals and radial aggregates of beryl. They are often found together with smoky quartz, &c. in the pegmatite of this region. The individuals attain more than

1 cm. in thickness. On some good crystals in Wada's collection, there are found $\circ P$, ∞P , P , &c. Optical anomaly consists of biaxial interference-figures in some part of basal sections. Corrosion-forms in the form of sharp-pointed pyramids with rounded edges are observed on the termination of some crystals.

TANOKAMIYAMA in Ōmi.—At this locality there is occasionally found greenish or bluish, transparent to translucent beryl, whose length is sometimes 13 cm. and whose basal section has sometimes a diameter of 3 cm. Good crystals of the beryl show P , ${}_2P_2$, $\circ P$, &c. In one specimen with unstriated prisms, there is to be seen on $\circ P$ a hexagonal pit which might have been produced by natural etching (Wada's collection).

117. Orthoclase and Microcline.

TANOKAMIYAMA in Ōmi.—The potash feldspars of this locality, which form druses in pegmatite, are separable into following varieties:

a.) White translucent crystals, usually in Carlsbad and Baveno twins, less frequently in Manebach twins and very seldom in simple crystals. The Carlsbad twins always look like simple crystals, for the $P\infty$ of one individual is nearly parallel to $\circ P$ of the other. They are usually smaller than the Baveno twins which attain a length of 20 cm.

b.) Reddish-white to flesh-red crystals, occurring with topaz.

c.) Glassy crystals mostly in Baveno twins, but rarely in simple individuals, about 3 cm. in diameter. These crystals are usually stained with manganese oxide. Less numerous than *a* and *b*.

d.) Minute platy aggregates of white or bluish-white crystals with curved faces.

Analyses of the varieties *a* and *b* by Kōdera are as follows :

	a	b
Si O ₂	64.78	64.62
Al ₂ O ₃	17.86	21.00
K ₂ O	12.87	12.22
Na ₂ O	2.25	2.41
Fe ₂ O ₃	1.46	0.33
Ca O	0.14	0.20
Mg O	0.11	0.09
	<hr/> 99.47	<hr/> 100.87

Two analyses of the variety *c* by the same chemist are as follows :

	I	II
Si O ₂	63.77	64.98
Al ₂ O ₃	19.52	22.17
K ₂ O	13.70	10.59
Na ₂ O	1.84	0.60
Fe ₂ O ₃	1.39	0.32
Ca O	<hr/>	<hr/>
Mg O	0.08	0.86
	<hr/> 100.30	<hr/> 99.52

The first sample was taken from a simple individual with an opaque-white internal part, and the second from a Carlsbad twin also with an opaque-white core. All the specimens, from which samples were taken for the above four analyses, are in Wada's collection.

Crystal faces in the varieties *a*, *b* and *c* of the potash feldspars of Tanokamiyama are $\infty P \infty$, ${}_0P$, ∞P , ∞P_3 , P , $P \infty$, ${}_2P \infty$ and ${}_2P \infty$; besides (according to Kō), $\infty P \infty$, found only in *a* and *b*.

Deviation of the angle PM from a right angle is sometimes very great ; this may be due to an imperfection in crystal development.

The Baveno twins are sometimes cyclical and consist of three individuals. A peculiar parallel-growth of two Baveno twins, with a re-entrant angle at their union, is not rare. That of two Manebach twins united on $\infty P\infty$ with a central depression on one end is also met with, but not often. Albite lamellæ in perthitic intergrowth are found in the potash felspar ; the same plagioclase making a parallel growth with principal felspar individuals, also forms crusts and projecting lamellæ on the faces of these.

NAEGI, &c. in Mino.—The varieties *a* and *d* above mentioned, are found, with the same characters and the same mode of occurrence, at Naegi and vicinity. The chief difference of these Mino crystals is their more decomposed and often opaque porcelain-like appearance. The peculiar parallel growth of two twinning crystals met with in Ōmi specimens has not been observed in them.

The form of termination of Baveno twins is of course different with different development of the faces. A specimen in our collection shows a nearly straight truncation.

KAI.—From a locality in Kai province were formerly brought large, glassy simple felspar crystals, about 9 cm. broad and showing $\infty P\infty$, ${}_0P$, ∞P , ∞P_3 , P , $P\infty$ and ${}_2P\infty$.

AKAZU in Owari Province.—White opaque simple crystals are collected at this locality, together with smoky quartz.

TADACHI in Shinano.—Light-greenish to greenish-grey microcline crystals with $\infty P\infty$, ${}_0P$, ∞P , $\infty P'$, $\infty P'_3$, $\infty P'_3$, ${}_1P$, P , ${}_1P\infty$ and ${}_2P\infty$ are collected in pegmatite, and attain a breadth of 7 cm. They occur along with good smoky quartz crystals.

MORAIYAMA in Shinano.—Iwasaki has described a number of partly decomposed potash felspar crystals from Moraiyama, collected by Ōkubo together with smoky quartz in a pegmatite. They are 2 to 4 cm. in length, and usually covered with brownish decomposition product. Observed crystal faces are $\infty P \infty$, ${}_0P$, ∞P , $\infty P \bar{3}$, P , $P \bar{\infty}$ and ${}_2P \bar{\infty}$. Simple crystals are rare; the specimens are usually in Baveno twins. The same twinning is sometimes repeated, thus producing twins of three or four individuals. Sometimes two Baveno twins are united, leaving a re-entrant angle at their union; and even four of them may unite causing a central depression on one end of the composite crystal. Albite lamellæ are enclosed in the crystals, but they are not visible with the naked eye, unlike some of the Ōmi and Mino specimens.

118. Albite.

Wada possesses a good specimen of albite druse found in Tosa Province. The white spots and grains in the chlorite-amphibolite of Kwantō are believed to be albite. Besides we have in the pegmatite of Ōmi and Mino, albite as crusts and lamellæ in potash felspars, and as minute crystal-aggregates.

119. Andesine.

SHIODA in Shinano.—Small crystals of this mineral, about 0.6 cm. long along the \tilde{a} axis, are found as porphyritic crystals in a compact grey plagioclase-rhyolite, which is almost entirely decomposed in yellowish-grey easily crumbling masses. Crystal faces are $\infty P \infty$, ${}_0P$, ${}_1P$, $\bar{\infty}$, $\infty'P$, $\infty P'$, $\infty'P_n$, and $\infty P'_n$. There are found rectangular, cross shaped, or broad tabular roundish forms of individuals. The last two forms are Carlsbad twins consisting

of two crystals, which are in themselves polysynthetic twins, either of the Albite or Pericline type, or of both at the same time. The rectangular crystal, as well as one half of the cross-shaped or broad-tabular twin, is apparently simple, but really shows grooves of the Pericline twinning and striations of the Albite twin. The presence of Manebach twins is doubtful; apparently complex crystals composed of many prismatic forms as in a cross-shaped twin, are nothing but irregular groups.

120. Labradorite.

Wada possesses a piece of grey labradorite from MINEOKA in Awa,* (Honshū); this specimen labradorizes distinctly in contrast to the plagioclase forming a constituent of the gabbro of this place.

121. Anorthite.

Kikuchi (Journal of the Science College of the Imperial University of Tōkyō, 1889) has given a detailed description of separate anorthite crystals of MIYAKEJIMA. They are perfectly developed on all sides and covered with a black coating of lava. Their form is thick tabular, either apparently simple or in Carlsbad twins. The longest diameter of the crystals is about 2 cm. Observed crystal faces are αP , $\infty P\infty$, $\infty'P$, $\infty P'$, $\infty'P\infty$, $\infty P'\infty$, βP , $\bar{\alpha}$, $\beta'P' \bar{\alpha}$, βP , $\bar{\alpha}$, $\beta'P' \infty$, $\beta'P \infty$, P' , βP , P , $\beta'P\beta$, $\beta P\beta$, $\beta P\beta$ and βP , (?), among which αP , $\infty P\infty$, βP , $\bar{\alpha}$, $\beta'P \infty$, and $\beta'P' \infty$ are most frequently found. Kikuchi has mentioned besides analysis by Kitamura, various artificial etching figures, principal optical characters, &c.

The same author found a similar anorthite in a volcanic rock of TŌNOSAWA in the old volcano of Hakone.

Numerous flat felspar crystals with rounded edges and a black coating were collected by Kikuchi at IWŌJIMA in the south-eastern corner of Japan. They are about 1 cm. long and seem to have been found in loose crystals just in the mode of the anorthite crystals of Miyakejima. The nature of this mineral has not yet been studied.

KŌSHINZAN near Ashio in Shimotsuke.—Saitō has found numerous good porphyritic crystals of anorthite in an agglomerate of this place. The largest individual measures about 15 cm. in length. Crystalline habit is thick columnar, with faces ∞P , $\infty' P$, $\infty P'$, $\infty' P'$, ∞P , $\infty' P$, $\infty P'$, $\infty' P'$, ∞P , $\infty' P$, $\infty P'$, $\infty' P'$.

122. Titanite.

At and near the mines of KAMIOKA in Hida, are found in diorite numerous, small, yellow-coloured titanite crystals. They are like a letter-envelope in shape, and measure sometimes 0.6 cm. in length. An analysis by Yoshida is as follows:

Si O ₂	30.81
Ti O ₂	40.21
Fe ₂ O ₃	0.51
Al ₂ O ₃	0.61
Ca O	26.42
Mg O	1.21
	<hr/> 99.77

At KINKWAZAN in Rikuzen, Kotō has found brown titanite crystals in granite.

123 Natrolite.

This mineral is found at OSAWA in Nikkō in Shimotsuke, MAZE in Echigo, SHIODA in Shinano, OHARA in Iwaki, &c.

At Nikkō the mineral has been found in fine short needles, together with chabasite, desmine and calcite, all of which occur in a dark-brown decomposed andesite.

At Maze, beautiful colourless needles of natrotite are associated with pretty druses of apophyllite and analcime, together with calcite, heulandite and chabasite, which are all found in a grey volcanic rock with amygdaloidal cavities.

At Shioda, a dark-coloured andesite-agglomerate contains apophyllite, heulandite, chabasite &c., together with radial groups and aggregates of natrolite, which sometimes show pyramidal endings.

The natrolite of Ohara is in the shape of felt-like aggregates found in andesite, together with heulandite druses and less numerous desmine, epistilbite (?), &c.

Optical anomaly of natrolites from the four above-mentioned localities consists of undulatory extinction of the needle-shaped individuals which are often apparently twisted.

124 Apophyllite.

SHIODA in Shinano.—Aggregates of small greenish-white crystals of apophyllite are sometimes found attached to natrolite aggregates of this locality. Less numerous than this apophyllite is a reddish-white variety in larger individuals, sometimes about 0.5 cm. in diameter. Both varieties show $\infty P \infty, P$, &c. and division into sectors, like that in the specimens from Golden in Colorado.

MAZE in Echigo.—Colourless to greenish-white partly transparent pyramidal crystals of apophyllite with $\circ P$, $\infty P \infty$ and P , sometimes measuring 5 cm. along the c axis, show the same optical anomaly as the apophyllites of Shioda. Crystal faces are sometimes covered with sub-individuals.

OGASAWARAJIMA.—Druses of white prismatic crystals of apophyllite with $\circ P$, $\infty P \infty$ and P (?), (besides ∞P_3 and $\frac{1}{3}P$, according to Kō), are found with heulandite in a green earthy mass of an altered eruptive rock (?). Basal sections of the crystals sometimes measure about 1 cm. or more in diameter. Some of the crystals show distinct "Andreasberg-rings," but no division into sectors in crossed Nicols. Others show biaxial interference figures, no division into sectors is there observed, but an intergrowth of irregular patches with a different orientation is found in the principal crystal substance.

Reddish-white apophyllite crystals of a more minute size are comparatively rare at the same locality. They show a combination of $\circ P$, P , $\infty P \infty$, and are nearly like the white crystals in the different phenomena of optical anomaly they exhibit.

The white crystals of Ogasawarajima have been analyzed.

125. Analcime.

MAZE in Echigo, which is the most well-known locality of Japanese analcime and apophyllite, gives crystals of the former mineral always in $2O_2$, with often striated faces and sometimes modified by $\infty O \infty$ at their solid angles. The mineral is colourless to greenish-white and is sometimes 2.5 cm. in diameter. Sections parallel to $\infty O \infty$, taken from the outer part of the crystal, usually show four sectors, besides rarely a central one. Similar sections from the middle of the crystal show eight subdivisions. Those parallel to O and taken from near the surface show three or six sectors; and those parallel to $2O_2$ and from the surface are often divided into three parts instead of being quite homogeneous. Double refraction is originally strong, and becomes stronger by heating.

126. Desmine and Epistilbite (?).

A few specimens of bundle-shaped zeolite from NIKKŌ and OHARA are probably desmine. At the latter locality we find, besides, small flat crystals about 0.6 cm. long, and showing a complicated division into sectors like the bundle-shaped specimen of the same place.

Small and very rarely observed specimens of flat prismatic crystals, about 0.6 cm. in length, in the compact andesite of OHARA were measured on the prismatic edges and found to be similar in crystalline habit to an epistilbite.

127. Heulandite.

OGASAWARAJIMA.—Nearly colourless crystals of heulandite, sometimes 2.5 cm. long (in the direction of the c axis), form druses at this locality, together with the already mentioned white apophyllite. The greenish tinge of this mineral is due to an admixture of green particles along the cleavage. Crystal faces observed in the specimens are $\circ P$, ∞P^{∞} , ∞P , $-2P^{\infty}$ and $2P^{\infty}$. Cleavage-lamella shows as many fields as there are sides to the section; these fields make transition to the middle field. The size of the middle field is larger in those lamellæ which have been taken from near the surface of the crystal. The extinction angle of each field is not constant even at the same temperature, a slight change of which produces a marked change in the optical orientation.

OHARA.—Yamasaki has described the heulandite of this locality, which measures in larger individuals about 0.8 to 1 cm. in length. Same crystal faces and optical anomaly, as in the specimens from Ogasawarajima, are here observed. The mineral is white and translucent. An analysis by Shinowara gave

Si O ₂	58.4
Al ₂ O ₃	14.4
Ca O	12.2
H ₂ O	14.9
	<hr/> 99.9

Heulandite occurs, besides, at SASEBO in Hizen (according to Kō), at MAZE in Echigo (according to Takimoto), &c.

128. Chabasite.

OSAWA in Nikkō.—Saitō has described the following characters of chabasite from this locality :

Crystals found in druses, more or less tainted with a brown ferruginous substance. Their diameter is about 1 or 2 cm. Numerous twins on R and a comparatively few supplementary twins are observed. Crystal faces are R and $-\frac{1}{2}R$, with $-\frac{1}{2}R$ in some individuals. Triangular section parallel to $\circ P$ is divided into six fields which are often quite irregular in boundaries. The corresponding chief sections of two fields lying on one of the corners of the section make an acute angle, opening towards that side of the triangle which is opposite to this corner. Sections parallel to R show a division into two fields, with inserted twin-lamellæ.

MITAKA in Izu.—M. Yamashita has studied minute colourless crystals of chabasite in a fresh greenish-grey coloured rock. Their diameter is only about 0.5 cm. Optical character is nearly like that of the Osawa specimens ; but good sections parallel to $\circ P$ are very difficult to prepare, for the crystals are usually attached to rock by their lateral solid angles.

Other localities of chabasite is in the province HIZEN, &c.



INDEX.

	PAGE.		PAGE.
1. Graphite	214	36. Cassiterite... ..	231
2. Sulphur	214	37. Pyrolusite	232
3. Arsenic	215	38. Corundum	232
4. Bismuth	216	39. Hematite	232
5. Platinum	216	40. Cuprite	232
6. Iridosmium	216	41. Tenorite	232
7. Copper	216	42. Opal	233
8. Silver	217	43. Mangunite... ..	233
9. Mercury	217	44. Limonite	233
10. Gold	217	45. Asbolane	234
11. Meteorite	217	46. Cerargyrite	234
12. Realgar, Orpiment.	218	47. Fluorite	234
13. Stibnite	218	48. Thomsenolite and Ralstonite	234
14. Bismuthinite	219	49. Calcite	235
15. Molybdenite	219	50. Dolomite	237
16. Zinc-blende	219	51. Magnesite	237
17. Pyrrhotite	220	52. Smithsonite	237
18. Pyrite	220	53. Rhodocrosite	238
19. Marcasite	221	54. Siderite	238
20. Arsenopyrite	222	55. Aragonite	238
21. Galena	222	56. Witherite	239
22. Argentite	222	57. Cerussite	239
23. Chalcosite	223	58. Malachite	239
24. Cinnabar	223	59. Azurite	240
25. Bornite	223	60. Psilomelane	240
26. Chalcopyrite	223	61. Barite	240
27. Matildite	223	62. Anglesite	242
28. Jamesonite	224	63. Wulfenite	242
29. Pyrargyrite	224	64. Scheelite	242
30. Fahlore	224	65. Wolframite	242
31. Stephanite... ..	224	66. Linarite	242
32. Stannite	224	67. Gypsum	243
33. Quartz	225	68. Malantherite	243
34. Tridymite	230	69. Alunite	243
35. Rutile	231		

	PAGE.		PAGE
79. Chromite	244	100. Zinnwaldite, Muscovite, &c.	260
71. Magnetite	244	101. Ottrelite	262
72. Chrysoberyl	244	102. Serpentine	263
73. Fergusonite	245	103. Tale	263
74. Monazite	245	104. Agalmatolite	263
75. Apatite	245	105. Nepheline	263
76. Pyromorphite	246	106. Cordierite	264
77. Adamine	246	107. Bronzite	264
78. Olivenite	246	108. Augite	265
79. Vivianite	246	109. Wollastonite	267
80. Erythrine	247	110. Hedenbergite	267
81. Scorodite	247	111. Diallage	268
82. Staurolite	247	112. Rhodonite	268
83. Hemimorphite	247	113. Tremolite	269
84. Andalusite	247	114. Hornblende	269
85. Sillimanite	248	115. Glaucophane	269
86. Cyanite	248	116. Beryl	269
87. Topaz	248	117. Orthoclase and Microcline ..	270
88. Tourmaline	252	118. Albite	273
89. Lievrite	252	119. Andesine	273
90. Epidote	253	120. Labradorite	274
91. Piedmonite	253	121. Anorthite	274
92. Orthite	253	122. Titanite	275
93. Vesuvianite	254	123. Natrolite	275
94. Olivine	254	124. Apophyllite	276
95. Danburite	254	125. Analcime	277
96. Garnet	255	126. Desmine and Epistilbite ...	278
97. Chrysocolla	258	127. Heulandite	278
98. Axinite	258	128. Chabasite	279
99. Biotite	259		



On the Mutual Influence between Longitudinal and Circular Magnetizations in Iron and Nickel.

By

K. Honda, *RIGAKUSHI*,
Post-Graduate in Physics.

With Plates XXIV & XXV.

The change of magnetization of iron and nickel wires due to electric current passing through them attracted the attention of several physicists. Marianini¹⁾ first observed the decrease in the moment of a permanent magnet by discharging a Leyden jar through it. The effect of longitudinal current on the intensity of magnetization of an iron wire placed in constant magnetizing field was examined by G. Wiedemann.²⁾ He arrived at the same result as Marianini, but he found further that when the current is broken, the magnetization is considerably increased. Villari³⁾ undertook similar experiments in connection with the effect which bears his name, and obtained analogous results. He concludes that longitudinal current increases the magnetization of soft iron in weak magnetizing fields and decreases it in the strong, and that on breaking the current, there is always increase of

1) Ann. de chem. et phys. **16**, 436, 1846.

2) Pogg. Ann. **117**, 213, 1862.

3) Pogg. Ann. **126**, 103, 1865.

magnetization. The experiment was repeated by Werner Siemens.¹⁾ He wound two coils on an iron tube, one about the wall of the tube and the other perpendicular to it; the result of thus magnetizing the tube both longitudinally and transversely at the same time, as examined by means of a magnetometer, led to a considerable diminution of longitudinal magnetization. This result was afterwards confirmed by the experiments of W. H. Schultze,²⁾ C. G. Knott,³⁾ and F. H. Pitcher.⁴⁾

The effect of longitudinal field on circular magnetization was also examined by Villari⁵⁾ with an iron tube. By passing a magnetizing current, the intensity of circular magnetization increased, and increased again when the current was removed.

The present investigation is, to a great part, the critical study of the results already obtained by these physicists.

I. Arrangement.

In the present experiment, the intensity of longitudinal magnetization and its change were measured by means of a magnetometer, while the circular magnetization was examined by the ballistic method.

The magnetometer consisted of a small bell magnet suspended in a thick copper case by a quartz fibre and provided with a plane mirror. It was placed due magnetic west of a magnetizing coil, and its deflection was read by means of a telescope and scale which was 1.90 m. apart from the magnetometer.

The magnetizing coil was 29 cm. long and wound in two

1) Berl. Monatsber. **23**, Juni 1881; Wied. Ann **14**, 685, 1881.

2) Wied. Ann. **24**, 643, 1895.

3) Phil. Mag. **30**, 244, 1890; Proc. Roy. Soc. Edinb. **18**, 124, 1891.

4) Phil. Mag. **47**, 421, 1899.

5) Mem. di Bologna [5] **2**, 443, 1892; Beibl. **17**, 670.

layers with copper wire of 1 mm. diameter, and gave the field of 29.5 C.G.S. units at the middle of the coil due to the current of one ampère. The internal diameter of the coil was 2.7 cm. and the external 3.4 cm. It was placed in horizontal position with its axis perpendicular to the magnetic meridian.

The strength of the magnetizing current was measured by Thomson graded galvanometer which was carefully compared with deciampère balance both before and after each experiment.

The ballistic galvanometer was of Wiedemann form, with copper damping. Its resistance was about 52 ohms, and its period of vibration was about 6 seconds. It was 4 m. distant from the magnetizing coil. The constant of the galvanometer was determined by means of a standard coil which was always placed in the secondary circuit. The last mentioned coil was wound in a single layer with fine copper wire on a glass tube, whose diameter was 2.724 cm. and had 500 turns. It was placed in another coil whose field at the centre due to the current of one ampère was 36.0 C.G.S. units, and the constant of the galvanometer was determined by the ballistic throw at the make and break of the current in the primary coil.

The ferromagnetics used in the present investigation had the following dimensions :—

1. Wire of Swedish iron :

length=21.00 cm.; diameter=1.34 mm.; demagnetizing factor=0.0019.

2. Tube of Swedish iron :

length=20.70 cm.; external diam.=0.416 ; internal diam.=0.335 cm.; demagnetizing factor=0.0063.

3. Tube of soft iron :

length=16.79 cm.; external diam.=0.966 cm.; internal

diam.=0.842 cm.; demagnetizing factor=0.0308.

4. Nickel tube :

length=17.02 cm.; external diam.=1.328 cm.; internal
diam.=1.252 cm.; demagnetizing factor=0.0261.

During the experiment, it was almost impossible to avoid the change of temperature due to circularly magnetizing current. It was thus necessary at the first step to determine the effect of temperature on the intensity of magnetization of iron or nickel wire between the temperatures 10° C and 100° C.

An iron wire was heated by passing steam through the space between two co-axial tubes of brass; it was placed in the axial line of the tubes, and the magnetizing coil was wound on the external tube. The effect of heating on the magnetization of iron is very small, the greatest change amounting only to 0.10 C.G.S. units per degree rise of temperature in the field of 21.2 C.G.S. units ($I=1060$ C.G.S. units). In fields less than 11 C.G.S. units, it is to increase and above that field to decrease the intensity of magnetization. With nickel wire, the character of the change of magnetization is similar with that of iron, but the amount of the change is comparatively large. The greatest increase of magnetization amounted to 0.35 C.G.S. units per degree rise of temperature in the field of 7.6 C.G.S. units ($I=121$ C.G.S. units). Thus the change of magnetization due to a small rise of temperature may be neglected for iron as well as for nickel.

The effect of torsional strain of iron or nickel caused by the magnetizing field and the longitudinal current on the intensity of magnetization was also carefully examined and found to be negligibly small.

To study the action of longitudinal current passing through the magnetized wire by the ballistic method, a secondary coil

was wound on a glass tube of external diameter 0.748 cm. with fine copper wire, and placed in the magnetizing coil, in the axial line of which the wire was placed. The wire was soldered to a brass wire (2 mm. in diameter and 10 cm. in length) at each end, through which longitudinal current entered or left the wire. The ballistic throw produced by passing a given longitudinal current gave the change in magnetization.

The smaller iron tube was not circularly magnetized by means of a current passing directly through the tube, but was placed in the magnetizing field due to a current through an insulated copper wire of 1.8 mm. diameter in the axial line of the tube. To avoid heating, cold water was kept constantly flowing through the interspace between the wire and the inner wall of the tube.

To measure the effect of longitudinal current on magnetization by the magnetometric method, we must eliminate the direct action of the current on the magnetometer. For this purpose, another copper wire of the same diameter was bent so as to form a rectangle 6 cm. by 36. This wire was fixed in the horizontal plane passing through the centre of the magnetizing coil, with



its longer sides parallel to the central line and symmetrical with respect to the centre of the coil as shown in the annexed figure. The central copper wire laid on V-shaped grooves of brass plates B and B' at the ends of the coil, and its terminals were dipped in small mercury pools, bored in the middle of these grooves. On the side of the magnetometer, a short copper wire

W (1 cm. in length) was placed parallel to and under the central copper wire to connect the middle point

of the shorter side of the rectangular copper wire with the brass plate B. The corresponding point on the opposite side of the copper wire and the brass plate B' on the same side were connected with the poles of an accumulator. The current thus entered the brass piece B', then flowed through the straight copper wire, and passed to two branches of the wire.

By this arrangement, the direct action of the current was nearly eliminated; the accuracy of the balance in the branches of the lead wire was tested before each experiment. The current flowing symmetrically with respect to the central line along each side of the rectangular wire produces nearly equal but opposite field on the iron tube, and is 3 cm. apart from it; hence the disturbance of the circularly magnetizing field would be insensible. This arrangement was found inconvenient for experimenting with thick tubes.

With larger iron and nickel tubes, I used another method of eliminating the heating by current. Each tube was wound uniformly with an insulated copper wire around the wall along its generating lines as to produce a nearly uniform circular field by a current passing through the wire, as was already done by Siemens and Schultze. The coil was protected by paraffin wax. It was then fixed in the central line of the magnetizing coil, and cold water kept constantly flowing in the tube.

The magnetization and its change were mostly measured by the magnetometric method. To determine them by means of the ballistic method, a secondary coil was wound on each tube. Placing the tube inside the magnetizing coil, and passing a current of cold water constantly round it, the change of longitudinal

magnetization due to a circularly magnetizing field was measured, and compared with that obtained by the magnetometric method. The results obtained by these two different methods nearly coincide, showing that there is no trace of the effect of heating as determined by the magnetometric method.

To investigate the effect of the longitudinal field on the circular magnetization of iron or nickel tube, I also wound very carefully a secondary coil over the circularly magnetizing coil and parallel to the tube, and measured the change by the ballistic method.

The total number of turns of the primary circularly magnetizing coil was 40 for the iron tube and 60 for the nickel tube, and the mean field due to the current of one ampère was 17.7 C.G.S. units for iron and 18.6 C.G.S. units for nickel. Owing to the thickness of these tubes, the greatest deviation of the field from the mean was 14 % for iron and 4.5 % for nickel. The number of turns of the secondary coil for the measurement of longitudinal magnetization was 303 for iron and 1,000 for nickel, and that for circular magnetization was 100 for iron and 302 for nickel.

II. Result of Experiments.

1. IRON WIRE.

The wire was first well annealed and put into the secondary coil, and the coil was then fixed in the central line of the magnetizing coil. After the wire was carefully demagnetized, it was placed in constant magnetizing field. The longitudinal current was then sent through the wire, and the corresponding throw of the ballistic galvanometer was read. The wire was again demagnetized and the same process repeated several

times by changing the strength of the longitudinal current. Since the deflection is almost instantaneous, the effect of heating would be negligibly small.

Three sets of observation for iron wire are given in the following table and in Fig. I. In this and the following figures, curves are drawn through every point obtained by experiments.

TABLE I.

IRON WIRE.

H=0.9		H=1.7		H=10.4	
Long. cur. per sq. cm.	δI	Long. cur. per sq. cm.	δI	Long. cur. per sq. cm.	δI
1.3	4	1.2	10	1.2	1
2.9	19	2.9	43	2.9	4
6.6	68	6.6	116	6.6	14
11.2	97	10.2	115	11.2	10
17.0	104	17.1	77	16.9	-17
30.2	95	30.5	4	30.5	-104
37.8	87	38.4	-30	38.5	-173
47.0	82	47.6	-61	44.4	-247

Here H denotes the effective magnetizing field, and δI the change of the intensity of magnetization. Currents are given in ampères.

The hysteresis attending cyclic changes of longitudinal current is shown in Fig. 2. The magnetizing field was 6.7 C.G.S. units and the corresponding intensity of magnetization was 684 C.G.S. units. When the cyclic state arrived, the initial intensity of magnetization increased to 827 C.G.S. units. The strongest current applied was only 35 ampères per square centimeter so that the effect of heating would be small.

2. SMALLER IRON TUBE.

In the first place, putting the auxiliary copper wire in the central line of the magnetizing coil, the direct action of the longitudinal current on the magnetometer was eliminated, and then the compensation of the magnetizing coil brought to perfection. Replacing the auxiliary wire by the iron tube which was carefully annealed, it was magnetized longitudinally, and then gradually increasing the axial current, the corresponding deflections of the magnetometer were noted. The strongest current used in this experiment was 40 ampères.

The following table contains 3 sets of the observed results; 6 curves for different magnetizing fields are given in Fig. 3.

TABLE II.

H=4.5		H=6.6		H=19.0	
Long. cur. in amp.	δI .	Long. cur. in amp.	δI .	Long. cur. in amp.	δI .
1.3	24.0	0.8	11.6	0.8	0.7
2.9	72.6	1.9	28.6	1.9	6.1
3.9	88.6	4.2	51.1	3.3	6.5
5.4	85.6	6.9	35.1	4.2	3.1
8.3	72.6	10.2	10.6	8.1	-30.3
11.7	61.4	11.5	8.2	11.3	-70.2
15.8	52.5	15.7	-11.9	15.3	-106.2
39.5	22.5	39.3	-57.9	39.4	-199.4

Next changing the order of magnetization, the tube was first circularly magnetized by a constant axial current, and then magnetized longitudinally, beginning with zero field up to about 60

C.G.S. units. The results are given in the following table and in Fig. 4.

TABLE III.

Long. cur.=0 amp.		Long. cur.=15.3 amp.		Long. cur.=40.9 amp.	
H	I	H	I	H	I
1.4	45	1.8	52	1.6	38
2.6	118	3.7	198	3.8	179
3.6	221	8.4	531	6.1	345
5.5	460	18.6	773	13.0	582
10.2	745	27.7	886	24.7	746
19.3	921	35.5	952	34.0	816
36.4	1044	44.4	1005	42.8	871
45.2	1085	57.9	1067	56.8	946

It is to be noticed that the intensity of magnetization in the longitudinal direction is, in this case, always less than that in the former case for the same longitudinal and transverse fields, as will be seen from Figs. 3 and 4.

Next keeping the longitudinal field constant, the axial current was changed cyclically between +12.5 and -12.7 ampères, and the hysteresis curve as shown in Fig. 5 was obtained. The magnetizing field was 11.6 C.G.S. units and the corresponding intensity of magnetization was 776 C.G.S. units. It increased to 845 C.G.S. units, when the cyclic state arrived.

The hysteresis curve attending the cyclic changes of longitudinal field, while the circular field is kept constant, is the same as the ordinary hysteresis curve, except that the area is considerably reduced, in accordance with what is well known.

3. LARGER IRON TUBE.

I first studied the behaviour of the tube by the magnetometric method. The magnetizing coil was well compensated, and the tube fixed in the central line of the coil; then closing both ends of the coil with cork, cold water was kept constantly flowing in the interspace.

The effect of transverse field on the intensity of magnetization in longitudinal direction is given in the following table and Figs. 6 and 7.

TABLE IV.

H=6.9			H=9.2			H=53.4		
h	δI	$\delta I/I$	h	δI	$\delta I/I$	h	δI	$\delta I/I$
1.0	44	0.092	1.2	18	0.023	2.0	2	0.002
2.0	52	0.107	2.0	26	0.032	3.0	3	0.002
3.0	64	0.132	3.0	36	0.045	6.7	-4	-0.004
6.6	54	0.112	6.7	8	0.010	13.3	-35	-0.028
13.1	19	0.040	13.3	-70	-0.087	28.4	-127	-0.104
27.8	-44	-0.091	27.4	-184	-0.228	40.0	-206	-0.168
39.0	-80	-0.166	39.0	-244	-0.302	53.8	-294	-0.240
54.3	-124	-0.256	49.2	-287	-0.355	74.9	-407	-0.332
83.5	-190	-0.392	73.9	-373	-0.462	88.9	-470	-0.384
104.0	-227	-0.470	95.6	-428	-0.530	103.8	-520	-0.425

Here H and I have the same meanings as before, and h denotes the transverse magnetizing field.

It is to be noticed that though the transverse magnetizing coil was wound round the wall of the tube very carefully along its generating lines, small longitudinal magnetization was still to be traced due to a current through the coil, when no magnetizing field in that direction was acting, so that this was corrected for each experiment. It is probably due to the magnetic æolotropy of the tube.

Although the longitudinal magnetizing field was kept constant, the effective part of the field must vary, because the change of longitudinal magnetization is necessarily accompanied by that of the demagnetizing force. The influence of the change on the intensity of longitudinal magnetization is considerable in weak fields, but not so prominent in strong fields. In weak fields, the effective part decreases by the application of transverse field, so that the increase of magnetization in weak fields is considerably reduced. In stronger fields, it is somewhat increased. Since the demagnetizing factor is very small for the iron wire and the smaller tube, the effect is not so remarkable as in the case of the larger tube. The small increase of magnetization, in weak fields, for the latter is mainly due to this cause. H in the tables I, II, IV denotes the initial effective field.

The same change was also measured by the ballistic method to assure the absence of the effect of heating when it was examined by the magnetometric method. Starting every time from a magnetically neutral state, I measured the change of magnetization by the ballistic galvanometer, and obtained the presupposed result. An example is given in the following table for the sake of comparison.

TABLE V.

H=3.1 (ballistic).		H=3.4 (magnetometric).	
h	δI	h	δI
1.2	13	1.0	13
3.2	47	2.0	32
6.9	56	3.0	53
14.3	42	6.7	51
22.2	33	13.3	40
30.4	25	28.2	22
44.2	13	39.5	11
56.6	7	54.8	-4
60.8	-3	76.1	-24

The magnetizing fields are not the same for these two cases, so that we can not find an exact coincidence between the corresponding values of δI , but we observe at the same time that the coincidence must become closer, if H were the same in these two cases. From this and other results, I find that the effect of heating of the transverse magnetizing coil is not sensible in the case of iron.

Using the magnetometric method, I next examined the change of longitudinal magnetization by altering the order of magnetizations. The tube was first placed in a constant circular magnetizing field, and then magnetized longitudinally from zero field up to 18 C.G.S. units. The results are given in the following table and in Fig. 8.

TABLE VI.

h=0		h=2.2		h=37.8	
H	I	H	I	H	I
1.1	27	1.0	23	1.0	22
2.4	85	1.6	55	2.6	76
3.1	169	2.1	93	4.7	171
3.8	257	3.0	173	6.9	261
4.4	346	3.6	260	—	—
5.1	426	4.7	420	—	—
6.8	644	7.0	662	—	—
10.0	842	9.6	815	10.7	371
13.3	963	11.7	883	14.6	467
17.7	1035	18.5	983	24.7	631

Here again, from Figs. 6 and 8 we observe that the intensity of magnetization is, in this case, always less than that in the former case for the same transverse and longitudinal fields, so that the increase in weak longitudinal fields soon vanishes when the transverse field is increased.

Figs. 1, 3 and 6 show that in all longitudinal magnetizing fields less than 55 C.G.S. units, the magnetization increases slowly at first, and then rapidly, till it reaches a maximum. Then the change of magnetization begins to decrease very slowly in weak longitudinal fields, but rapidly in the stronger, and finally becomes less than its initial value. The decrease of magnetization in strong transverse or circular fields tends to approach a certain limiting value as the field is increased.

The transverse field at which the change of magnetization attains a maximum value decreases slowly as the longitudinal field is increased; and the point at which the change of magnetization vanishes recedes rapidly towards the origin as the longitudinal field is increased.

For weak longitudinal fields, the change of magnetization is linearly related to the strength of circular field, if it is not very weak. In strong transverse fields, the decrease of magnetization reaches a maximum and then again diminishes as the longitudinal field is increased.

If the axial current be broken gradually or suddenly, the intensity of magnetization always increases to a value greater than the initial. In weak fields, the increase is very great, amounting sometimes to double its initial value.

Fig. 7 shows that the value of $\partial I/I$ is comparatively large in weak fields, but decreases rapidly as the longitudinal field is increased. Hence the rate of increase of magnetization increases as the longitudinal field decreases, till it reaches a certain value, beyond which the rate again diminishes.

Figs. 4 and 8 show the curves of longitudinal magnetization when different circular fields are in action. Here the magnetization in low fields is increased when the transverse field is weak. In strong fields, it decreases for all transverse fields.

The hysteresis curves shown in Figs. 2 and 5 are similar in appearance with that of torsion,¹⁾ but as will be seen hereafter, it arises from an entirely different cause. The symmetry of the

1) Phil. Trans. 1878; Reprint of Papers, Vol. II. P. 330.

curves with respect to the axis of ∂I shows that the change of longitudinal magnetization is independent of the direction of the transverse field, as first observed by Wiedemann.¹⁾

The experiments of several previous investigators on this subject are somewhat discrepant. As was already mentioned, G. Wiedemann noticed only decrease of magnetization; Villari observed an increase of magnetization by passing a current through an iron bar placed in a constant longitudinal field of moderate strength, and a decrease in a strong. He²⁾ also found a decrease of magnetization in strong circular field, and the discordance between the two was ascribed to the effect of heating by the current. On the other hand, Knott, Siemens, Schultze and Pitcher did not observe any increase of magnetization.

All these results are however not altogether discordant, and can be easily reconciled from the results of the present experiment.

I shall next describe the experiment on the effect of longitudinal field on circular magnetization.

The magnetizing coil was so placed that it gave no effect on the galvanometer. Putting the tube in the magnetizing coil and demagnetizing it by reversals, the effect of longitudinal field on the circular magnetization, when there is no circularly magnetizing field, was first examined by the ballistic method. The effect was very small and can be easily corrected. Keeping the circular magnetizing field constant, the tube was longitudinally magnetized with the following result.

1) loc. cit.

2) loc. cit.

TABLE VII.

h=2.5		h=6.2		h=18.3		h=55.1	
H	δI	H	δI	H	δI	H	δI
0.0	0	0.0	0	0.0	0	0.0	0
2.1	110	2.1	23	2.2	3	2.2	3
3.2	214	3.2	34	3.2	1	3.2	-3
5.2	296	5.1	0	5.1	-27	5.1	-24
8.5	272	8.9	-103	8.5	-86	8.5	-52
15.7	176	15.9	-240	15.4	-172	15.4	-87
30.9	90	32.3	-390	32.0	-316	31.7	-153
38.2	79	40.3	-421	39.8	-661	39.1	-175
45.5	76	47.5	-440	46.8	-407	47.1	-195
64.0	58	65.4	-486	65.9	-483	65.9	-266
74.2	52	103.5	-536	76.7	-523	102.4	-379

To calculate H , we must subtract from the external field the demagnetizing force corresponding to the intensity of magnetization when the circular field is acting; but in the above table, I only took account of the demagnetizing force corresponding to no circular field, so that there will be some difference in the value of H .

From the above table, we see that the general nature of the change of magnetization is the same as that already described. In the present case, the demagnetizing force in the direction of circular magnetizing field does not exist, and therefore h remains constant during the application of longitudinal field; hence we must

have greater increase of magnetization in weak longitudinal fields than in the former experiment. The large increase of magnetization in the weak field $h=2.5$ C.G.S. units must partly be due to this cause.

It was still a question whether the magnetizations in the longitudinal and transverse directions were equal, as the isotropy of the material was not well ascertained, and moreover the magnetized body was a toroid as regards circular magnetization, while with respect to longitudinal magnetization, it was a hollow cylinder. To settle this point, the magnetizations in these two directions were measured with the following result :

TABLE VIII.

H	I (long.)	H	I (circul.)
1.0	23	0.7	12
1.8	59	2.0	43
2.6	141	2.7	334
3.6	367	6.7	767
5.2	594	12.8	903
7.6	828	19.8	962
9.9	919	26.9	1004
20.3	1083	37.3	1056
31.9	1154	59.3	1131
70.7	1281	76.1	1175
88.3	1317	88.7	1200
114.3	1360	108.7	1243

The curve of circular magnetization is steeper than that of the longitudinal as seen from Fig. 9 ; hence the increase of circular magnetization in weak fields must be greater than that of longitudinal magnetization for the same field strengths for the reason here-

after given. The large increase of magnetization in the weak field noticed in the preceding experiment is to be explained partly by the difference in the behaviour of the longitudinal and circular magnetization. The difference in the decreases of magnetizations in longitudinal and transverse directions in strong fields is also due to the cause just mentioned as well as to the absence of demagnetizing force in the transverse direction.

Villari only observed increase of magnetization in the transverse direction by applying axial magnetizing fields, because his fields were too weak. Thus the effect of longitudinal field on circular magnetization is the same as that of circular field on longitudinal magnetization.

4. NICKEL TUBE.

The change of magnetization in longitudinal direction due to transverse field was examined by the magnetometric method as was done with the iron tube. The results are given in the following table and in Fig. 10.

TABLE IX.

H=6.6			H=9.2			H=23.2		
h	δI	$\delta I/I$	h	δI	$\delta I/I$	h	δI	$\delta I/I$
6.8	15.6	0.083	6.9	10.8	0.036	3.1	1.6	0.004
13.9	30.5	0.161	13.8	23.7	0.078	6.9	2.3	0.006
21.1	43.2	0.229	28.6	23.5	0.078	13.8	3.2	0.008
28.6	52.2	0.276	39.1	7.6	0.025	28.6	-9.7	-0.024
39.0	53.1	0.281	47.6	-14.2	-0.047	39.2	-26.9	-0.066
58.7	13.1	0.069	58.7	-45.3	-0.150	58.5	-70.4	-0.173
73.0	-27.6	-0.146	74.8	-97.2	-0.321	81.9	-132.3	-0.325
88.6	-63.9	-0.338	90.7	-141.6	-0.467	90.5	-155.0	-0.380

The same effect was also measured by the ballistic method. The results obtained by these two different methods agreed fairly well with each other, showing that the effect of heating of the coil, if any, must be very small even for nickel, as the following table will show :

TABLE X.

H=15.6 (ballistic)		H=14.9 (magnetometric)	
h	δI	h	δI
3.4	0.8	6.9	4.6
6.5	1.2	13.8	5.3
16.1	2.5	21.3	3.5
26.8	-2.8	28.6	-3.7
38.7	-16.0	39.0	-22.7
61.8	-67.3	47.7	-43.9
73.5	-102.2	58.7	-72.6
85.5	-140.0	75.1	-122.1
93.8	-166.7	91.2	-167.7

By the magnetometric method, I also measured the magnetizations with constant circular fields, the result of which is graphically shown in Fig. 11.

The hysteresis attending the cyclic changes of transverse field is shown in Fig. 12. The dotted line represents successive steps, till the change becomes at last cyclic.

Figs. 10, 11 and 12 show that the general feature of the change of magnetization is the same as that for iron. Although there is some difference in quantitative details, the qualitative results are generally common to iron and nickel.

The remarkable difference between iron and nickel lies in the field strength at which the increase of magnetization reaches a maximum. Such a field in nickel is, in the present experiment, greater than 35 C.G.S. units in weak longitudinal fields, while in iron it is about 4 C.G.S. units.

Next I shall describe the result of experiments on the effect of longitudinal field upon the transverse intensity of magnetization measured by the ballistic method. Proceeding as in the case of iron, I obtained the following numbers:

TABLE XI.

h=6.7		h=20.9		h=41.4	
H	δI	H	δI	H	δI
0	0	0	0	0	0
3.4	3.3	3.4	11.3	3.4	5.0
6.4	11.2	6.3	19.2	6.3	0.4
15.9	10.0	15.9	0.8	15.9	-40.6
31.1	3.8	31.9	-18.9	31.9	-59.3
49.3	-2.1	50.6	-36.0	50.6	-113.9
59.3	-9.2	88.9	-58.9	88.6	-159.0
77.7	-11.9	117.0	-67.2	102.1	-171.5
97.8	-14.2	131.0	-75.2	131.0	-190.5
143.3	-16.4	147.5	-79.9	146.6	-198.8

Here, in the calculation of H, the demagnetizing force corresponding to the magnetization with no circular field was only taken into account as in the case of iron.

The general feature of the change of magnetization is the same as in the former experiment. In this case, however, the increase in weak fields is generally small. As was the case with iron, the

large increase of magnetization must have taken place in the above experiment, because the demagnetizing force in the direction of circularly magnetizing field does not exist. That this was not the case is to be ascribed to the magnetic æolotropy of the nickel tube. The tube was made of a plate 6.5 mm. thick. It was well annealed both before and after the hole was bored; but the æolotropy was, notwithstanding, still to be traced. This and the geometrical shape of the tube are the causes of the difference in longitudinal and circular magnetizations as shown in the following table:

TABLE XII.

H	I (long.)	H	I (circul.)
0.9	33.7	2.9	12.6
2.1	58.0	6.5	28.0
4.2	99.6	13.2	61.5
6.2	221.4	20.5	103.7
10.4	359.3	26.5	145.9
16.1	396.0	36.6	204.9
22.5	416.0	57.1	308.5
42.5	446.5	72.7	365.7
55.9	456.8	83.1	393.3
98.2	473.7	96.9	419.3
144.4	482.3		

These numbers plotted against H are given in Fig. 13. The longitudinal magnetization in the above table was measured by the magnetometric method, that determined by the ballistic method being almost coincident. It does not seem probable that the æolotropy can be entirely effaced simply by the process of annealing. The result here obtained is confirmed by the ex-

periment of E. Rhoads¹⁾ on the effect of fibrous structure introduced by rolling thin iron plate, with regard to the intensity of magnetization and the change of length by magnetization. From Fig. 13, we see that the curve of circular magnetization resembles that of steel; hence it is to be expected, that the change of circular magnetization by longitudinal field is comparatively small. In general, the change of magnetization is less with harder (magnetically) iron or nickel.

It was also observed in the iron and nickel tubes that the intensity of circular magnetization when we first magnetize it circularly and then longitudinally is always greater than when the order of magnetizations is reversed.

III. Theory.

From the molecular theory of Weber, W. Siemens²⁾ concluded that the magnetization in a given direction should be different, according as the field perpendicular to that direction exists or not, and that in strong fields near saturation the magnetization must diminish.

G. Wiedemann³⁾ also deduced the same conclusion from the hypothesis of molecular magnets, and added that in weak fields magnetization increases.

Using the equations established by Poisson and Kirchhoff, W. H. Schultze⁴⁾ concluded that the magnetization in a given direction must increase by applying a magnetizing force perpendicular to it,

1) *Phy. Rev.* **7**, 1898, 65.

2) *loc. cit.*

3) Wiedemann's *Electricität*, **3**, 725.

4) *loc. cit.*

when the resultant field is less than that corresponding to the maximum susceptibility of iron, and that it must decrease, when the former field is greater than the latter.

Proceeding from a similar idea as Schultze, I believe that all the phenomena observed in the present experiment can be explained in the following manner.

Suppose the ferromagnetics to be isotropic, and to have no residual magnetism; then the intensity of magnetization at any point can be expressed in the form

$$I=f(H),$$

where H is the resultant field. Taking H for the abscissæ and I for the ordinates, the curve $I=f(H)$ represents that of magnetization.

Now let there be magnetizing forces l and t acting in perpendicular directions, then if $H = \sqrt{l^2 + t^2}$, we have

$$I=f(\sqrt{l^2+t^2}),$$

the component of which along l is

$$i=I\cos(H,l)=f(\sqrt{l^2+t^2}) \frac{l}{\sqrt{l^2+t^2}};$$

hence if k be the susceptibility, we have

$$i=kl.$$

If we suppose that l is kept constant and t is changed,

$$\frac{\partial i}{\partial t} = l \frac{\partial k}{\partial t} = l \frac{\partial k}{\partial H} \frac{\partial H}{\partial t} = \frac{lt}{H} \frac{\partial k}{\partial H},$$

from which we see that the whole phenomenon depends upon the change of k considered as function of H .

Now we know that k increases at first, till it reaches a maximum, and then gradually decreases; hence so long as the resultant field H is less than the field corresponding to the maximum susceptibility, the value of $\frac{\partial i}{\partial t}$ is always positive, so that there must be increase of magnetization in the direction of l by increasing t . When H is greater than that field, $\frac{\partial i}{\partial t}$ is negative, and we have decrease of magnetization. When H becomes just equal to that field, $\frac{\partial i}{\partial t}$ is zero, and the value of i reaches a maximum. This field is determinate for a particular substance, so that the value of t corresponding to the maximum value of i must diminish when l is increased, such that $l^2 + t^2$ is constant.

In soft iron or nickel, $\frac{\partial k}{\partial H}$ in weak fields is greater than that for harder one; hence increase of magnetization in weak fields for the former metal is greater than that for the latter, as already remarked.

The convexity or concavity of the curve of i plotted against t will be seen from the sign of the expression

$$\frac{\partial^2 i}{\partial t^2} = l \left(\frac{t}{H} \right)^2 \frac{\partial^2 k}{\partial H^2} + \left(\frac{l}{H} \right)^3 \frac{\partial k}{\partial H}.$$

From the experimental values of $\frac{\partial k}{\partial H}$ and $\frac{\partial^2 k}{\partial H^2}$, we see that when l is small and less than the critical field, $\frac{\partial^2 i}{\partial t^2}$ is at first positive, but it soon becomes negative, and when t is still further increased, it again changes its sign. When l is greater than the critical field, $\frac{\partial^2 i}{\partial t^2}$ is negative at first, and passing an inflexion point, it changes sign.

Thus when l is less than the critical field, the curve is at first convex towards the axis of t ; but it soon becomes concave towards the same axis. When t is further increased, it again becomes convex. When l is greater than the critical field, the curve is at first concave and then becomes convex towards the axis of t in strong fields.

In the above considerations, we have supposed our ferromagnetics to be magnetically isotropic and to have no residual magnetism; but these suppositions are not admissible for iron or nickel tube. Moreover we have not considered the variation of the effective part of the longitudinal field caused by the change of demagnetizing force with increasing transverse field. Hence we can not, strictly speaking, compare the above results with those obtained by experiments. But qualitatively all these points just mentioned are verified in the present experiment, as shown by Figs. 1, 3, 6 & 10.

In order to get a clearer insight of the phenomenon, I compared the result calculated from the curve of longitudinal or circular magnetization by the above considerations with that obtained by experiments. The comparison was made only in strong longitudinal fields, in which the suppositions introduced in the theoretical consideration were comparatively small. In general, the change of magnetization in weak transverse fields fairly agrees with theory, but in the strong, the deviation becomes more pronounced. By taking the theoretical results calculated from the circular magnetization instead of the longitudinal, the coincidence between theory and experiment becomes closer, especially in strong fields. These results are given in the following table :

TABLE XIII.

SMALLER IRON TUBE.

Cur. in amp.	H=19.0		H=40.7	
	∂I (exp.)	∂I_1 (theor.)	∂I (exp.)	∂I_1 (theor.)
2	7	-9	4	-2
4	4	-21	3	-6
8	-30	-61	-10	-18
15	-103	-168	-63	-56
25	-162	-310	-128	-130
40	-201	-435	-181	-254

LARGER IRON TUBE.

h	H=27.8			H=53.4		
	∂I (exp.)	∂I_1 (theor.)	∂I_2 (theor.)	∂I (exp.)	∂I_1 (theor.)	∂I_2 (theor.)
10	-32	-55	-47	-17	-19	-17
30	-219	-322	-280	-138	-143	-128
50	-353	-522	-454	-271	-307	-271
70	-454	-651	-572	-383	-445	-399
90	-526	-736	-647	-475	-561	-495

The theoretical values of the change of magnetization in the above table were simply obtained graphically from the curves of magnetization: ∂I_1 from the longitudinal and ∂I_2 from the circular magnetization. With the smaller iron tube, the field due to axial current c at a point distant r from the axis was calculated on the supposition that it is equal to $\frac{2c}{r}$. This assumption is evidently a rough approximation.

Since the æolotropy of the nickel tube is considerable, the values deduced from the circular and the longitudinal magnetizations are widely discordant with each other and also with the experimental results. But in strong longitudinal fields, the experimental and the theoretical results obtained from the curve of circular magnetization agree fairly well.

One of the principal causes of the discrepancy between theory and experiment lies in the fact that in deducing the theoretical conclusion, I have not taken account of the æolotropy. As I have observed, the intensity of magnetization in a longitudinal direction, when longitudinal and transverse fields, l and t , act simultaneously, is expressed by kl , where k is the susceptibility corresponding to the resultant field $\sqrt{l^2+t^2}$. Hence a small change in the curvature of the curve of magnetization has a great influence upon the intensity of longitudinal magnetization, and thus it is easily seen that the supposition of isotropy leads to a discordant result.

In nickel, the field at which the change of longitudinal magnetization by transverse field reaches the maximum was far greater than in iron. This arises also from the magnetic susceptibility of the nickel tube. By applying a gradually increasing transverse field to a weak longitudinal field, the direction of the resultant field rapidly inclines towards that of the transverse field. Hence under weak longitudinal fields, the magnetization by the resultant field resembles that of the circular field rather than that of the longitudinal. Since the susceptibility of the nickel tube by circular magnetization increases in comparatively slower manner than in iron, the maximum increase of the longitudinal magnetization must recede into higher circular field. Thus the occurrence of the maximum increase of longitudinal magnetization

in high fields is not characteristic for nickel; with a magnetically softer nickel, it would recede towards a weak field as in the case of iron.

Another principal cause of the discrepancy is the effect of residual magnetism. When the longitudinal field is kept constant and the transverse field is gradually increased, the residual magnetism due to the gradual change of direction of the resultant field must have some effect on the successive resultant intensity of magnetization. This effect we shall now proceed to consider.

It was found by experiments that magnetization of iron or nickel in a given direction was very little affected by the existence of residual magnetism in the same direction at the beginning of magnetization, provided the magnetizing field is not less than that which caused the residual magnetism. Let us now consider any two consecutive stages of applying transverse fields, and let I_1 and I_2 be the corresponding intensities of magnetization. We shall then investigate the contribution of I_1 as a residual magnetism on the formation of I_2 . We resolve the residual magnetism due to I_1 into two components, one along and the other perpendicular to the intensity of magnetization I_2' which gives I_2 when acted on by the residual magnetism. Of these two, the parallel component very little affects the intensity of magnetization, as we have seen from experiments. The only effective part is the component perpendicular to I_2' , the action of which tends to change its direction. Hence we may conclude that in whatever manner the residual magnetization may act, it is only to prevent the shifting of the direction of magnetization towards that of the resultant field. The intensity of magnetization in the longitudinal or transverse direction of our tubes must therefore depend on the

order of application of the two perpendicular fields. This was verified experimentally for each tube.

The magnetic æolotropy also causes the direction of the resultant field to differ from that of the corresponding magnetization ; but as will be seen from the present experiment, the effect is very small.

In strong longitudinal fields, the demagnetizing force diminishes with increasing transverse field, and therefore the effective part of the field increases, so that the intensity of longitudinal magnetization becomes greater than if the longitudinal field were constant. This influence can also be traced in the preceding table.

The transverse field also appears to produce molecular disturbance, and tends to increase the magnetization. It is generally very small in comparison with other effects.

Thus we have three principal causes of the discrepancy between theory and experiment, i.e., the magnetic æolotropy, the residual magnetism and the change of the demagnetizing force.

G. Wiedemann¹⁾ explained the large increase of magnetization, when the transverse field is removed, by the instability of molecular magnets caused by releasing the transverse field. The increase is also explained by residual magnetism ; if we subject the ferromagnetics to a gradually increasing transverse field, while the longitudinal field is kept constant, it will be strongly magnetized, and therefore when the transverse field is gradually or suddenly removed, there must remain a large amount of residual magnetism and hence we observe a large increase of magnetization. That the increase becomes greater as the longitudinal field diminishes, amounting sometimes to double its initial value,

1) loc. cit.

gives an additional evidence to the above explanation. Moreover that a sudden break of the transverse field gives less increase of magnetization than a gradual diminution, and that the increase becomes greater and greater as the transverse field is increased, however slow the breaking process may take place, seem to favor the explanation.

SUMMARY.

The following is a summary of the results of experiments.

RESULTS IN IRON.

1) In constant longitudinal fields, the magnetization, so long as the field is weak, of iron wire or tube increases at first, till it reaches a maximum, and then decreases to a value less than the initial, by applying a gradually increasing transverse field.

2) In fields greater than 55 C.G.S. units, the magnetization in the longitudinal direction decreases from the outset.

3) The effect of longitudinal field on the intensity of transverse magnetization is exactly the same as the effect of transverse field on the intensity of longitudinal magnetization.

4) By first applying the magnetizing field either in the direction of the tube or perpendicular to it, and then another perpendicular to *it*, the magnetization in the direction of the first application of the field is always greater than when the order of magnetizations is reversed.

5) The change of longitudinal or transverse magnetization by transverse or longitudinal field is independent of the direction of the field.

6) The hysteresis curve attending the cyclic change of the transverse field, while the longitudinal field is kept constant, is

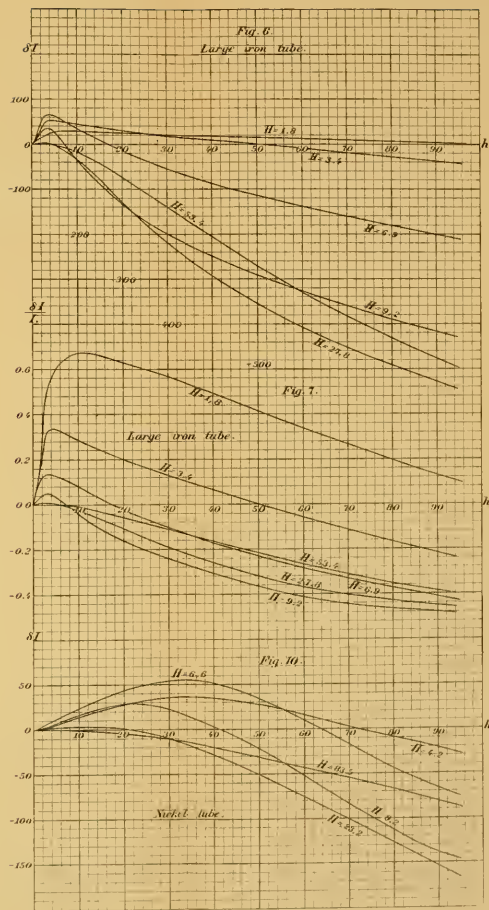
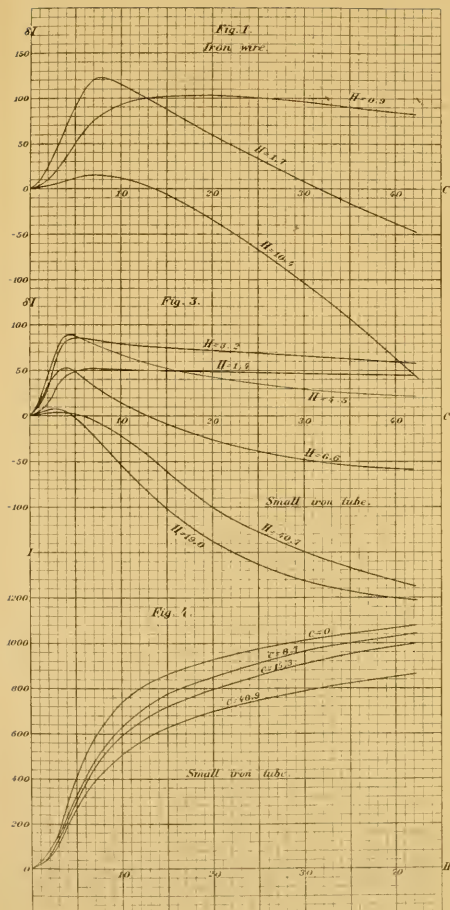
similar to that of torsion. The hysteresis by the cyclic change of the longitudinal field, while the transverse field is kept constant, is the same as the ordinary hysteresis, except that the area of the loop is considerably reduced.

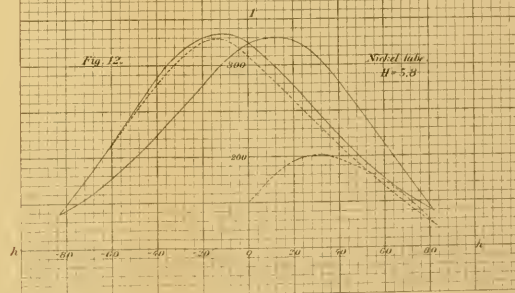
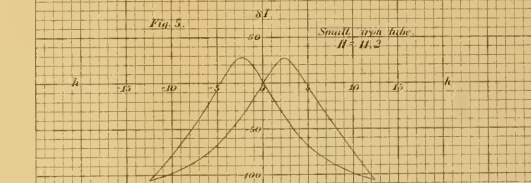
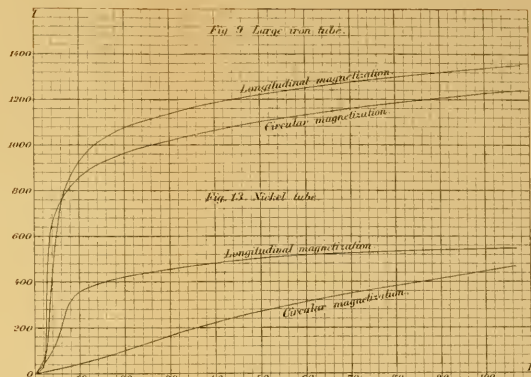
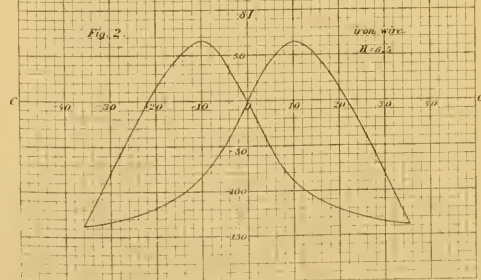
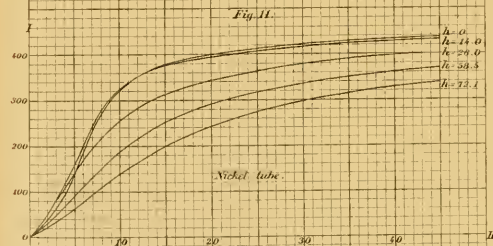
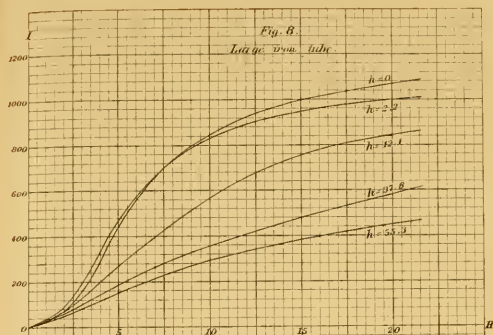
RESULTS IN NICKEL.

7) With regard to the effect of transverse field on longitudinal magnetization and that of longitudinal field on transverse magnetization, nickel behaves qualitatively like iron; but the effect is generally small. The hysteresis curves have also similar forms as in the case of the former metal.

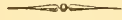
In conclusion, I wish to express my thanks to Prof. H. Nagaoka, under whose direction this investigation was carried out, and also to Prof. A. Tanakadaté for useful suggestions, and to Messrs. D. Sudo and S. Sano for kind advice and assistance in carrying out the present experiments.







ERRATA.



e

- p. 320. Eqke No. 7 ; Intensity. *For* III, *read* II.
 „ Eqke No. 8 ; „ „ „ „ „ „
 „ Eqke No. 10 ; „ „ „ „ „ „
 „ Eqke No. 20 ; „ „ „ „ „ „
 „ Eqke No. 22 ; District. *After* Iyo, Tosa, Izu, Yamato, etc., *insert* with
 sea-waves along the coasts of Tosa and Izu.
 p. 321. Eqke No. 41 ; Intensity. *For* III, *read* II.
 „ Eqke No. 49 ; District. *After* Mino, *insert* after-shocks continued for three
 days.
 „ Eqke No. 50 ; Intensity. *For* I, *read* III ?
 p. 332. Eqke No. 369 ; Intensity. *For* II, *read* III.
 „ Eqke No. 374 ; District. *For* (,,), *read* Suruga, the Fuji-san erupted.
 p. 333. Eqke No. 377 ; District. *For* (,,), *read* Higo, the Aso-san erupted.
 „ Eqke No. 378 ; District. *For* (,,), *read* Kyoto.
 „ Eqke No. 399 ; Intensity. *For* I, *read* III ?
 p. 334. Eqke No. 418 ; District. *After* Mitsu, *insert* accompanied by sea-waves.
 p. 342. Eqke No. 636 ; Intensity. *For* III, *read* II.
 p. 345. Eqke No. 723 ; District. *For* (,,), *read* Nara, strongly felt in Kyoto.
 „ Eqke No. 724 ; District. *For* (,,), *read* Kyoto.
 „ Eqke No. 737 ; Intensity. *For* III, *read* II.
 p. 351. Eqke No. 891 ; District. *After* Suruga, *insert* the Fuji-san erupted.
 p. 354. Eqke No. 976 ; Intensity. *For* III, *read* II.
 p. 370. Eqke No. 1416 ; European Date. *For* 1576, *read* 1578.
 p. 377. Eqke No. 1610 ; Intensity. *For* III, *read* II.
 p. 381. Eqke No. 1702 ; Intensity. *For* III, *read* III ?
 p. 386. Eqke No. 1861 ; District. *For* Omi, *read* Yedo.
 p. 392. Table I. Eqke No. 9 ; European Date. *For* 737, *read* 742.
 p. 394. „ Eqke No. 58 ; District. *After* Suruga, *insert* the Fuji-san erupted.
 p. 396. „ Eqke No. 113 ; District. *For* Kyoto and Satsuma, *read* Satsuma,
 slightly felt in Kyoto.

n 1893
 un, and
 at zeal
 om bad
 nguish-
 ot live
 lace in
 carried
 and is
 alogue,
 anese
 les and
 ; earth-
 l 1867,
 to the
 quakes

The Earthquake Investigation Committee Catalogue of Japanese Earthquakes.

SUPERINTENDED BY THE LATE

Prof. **S. Sekiya.**

PREFACE.

The Earthquake Investigation committee instituted in 1893 the compilation of facts relating to earthquakes in Japan, and the work was superintended by Prof. S. Sekiya with great zeal and ability, although he was all the time suffering from bad health. It is extremely to be regretted that this distinguished scientist, who did so much for seismology, did not live to finish the undertaking, his death having taken place in January 1895. The collection of earthquake literature, carried on by Mr. M. Tayama, was, however, steadily continued and is now gradually approaching completion. The following Catalogue, which has been compiled from 427 different kinds of Japanese histories, monographs, and unpublished original chronicles and journals, gives the dates, districts and intensities of 1898 earthquakes¹ in Japan during the 1451 years between 416 and 1867, and is to be regarded as a kind of table of contents to the complete compilation of detailed accounts of Japanese earthquakes

¹) Counting as only one each great earthquake and its after-shocks.

to be published before long in the reports of the Earthquake Investigation Committee.

The scale of intensity of earthquake motion adopted in the Catalogue is as follows :

- (1) *small or slight earthquakes*, in which the motion was weak, and which caused neither alarm nor damage ;
- (2) *strong earthquakes*, in which the motion was sufficiently sharp to cause people to run out of doors and to produce slight damage, such as the overthrowing of furnitures, small cracks in walls, *ishigaki* (masonry walls), embankments, etc ;
- (3) *great or destructive earthquakes*, in which the ground was cracked, buildings greatly damaged, lives lost, etc.

In the Catalogue these three classes are severally distinguished by the Roman numerals, I, II and III'.

There exist in some cases more or less complete records of the after-shocks of great earthquakes. In the Catalogue, however, all these shocks have, for the sake of simplicity, been excluded, in so far as they could be ascertained to be such. Again, volcanic eruptions and sea-waves are not given, unless when accompanied by earthquakes. The catalogues of these two natural phenomena in Japan shall form the subjects of future work.

The only other general catalogue of historical Japanese earthquakes is that given by the late Mr. H. Okajima in his "Nippon Saiishi," or *A History of unusual natural phenomena in Japan*,² which includes 1368 earthquakes and was compiled from 213 different works of reference. Lastly, I may also call atten-

1) See also §§ 2, 3 and 4 of the next paper.

2) Printed in 1894, after the death of Mr. Okajima.

tion to the three valuable papers on historical Japanese earthquakes by Messrs. Naumann,¹ I. Hattori² and John Milne.³ As an addition to these papers, I append to the present Catalogue a full discussion on the time and space distribution of earthquakes in Japan.

Feb., 1899.

F. OMORI.

SEISMOLOGICAL INSTITUTE, TOKYO.

1) *Dr. Naumann.* Ueber Erdbeben und Vulkanausbrueche in Japan. *Mittheilungen der Deutschen Gesellschaft für Natur-und Völkerkunde Ostasiens.* August, 1878.

2) *I. Hattori.* Destructive Earthquakes in Japan. *Trans. Asiatic Soc. Japan*, vol. VI, part II.

3) *John Milne.* Note on the great earthquakes of Japan. *Trans. Seis. Soc. Japan*, vol. III.



A CATALOGUE
OF
EARTHQUAKES IN JAPAN
BETWEEN
416 and 1867.

No.	EUROPEAN DATE.			JAPANESE DATE. ¹				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1	416	8	23	Inkio-Tenno.	5	7	14	III	Kawachi.
2	599	5	28	Suiko-Tenno.	7	4	27	III	Yamato.
3	642	11	8	Kokyoku-Tenno.	1	10	8	I	"
4	"	"	9	"	"	"	9	I	"
5	"	"	24	"	"	"	24	I	"
6	644	(Spring)		Tenchi-Tenno.	3	(Spring)		I	"
7	675	11		Temmu-Tenno.	3	11		III	"
8	677	7	22	"	5	6	14	III	"
9	678	1		"	6	12		III	Chikushi.
10	679	11	22	"	7	10	11	III	Yamato.
11	"	12	24	"	"	11	14	I	"
12	680	10	24	"	8	9	23	I	"
13	681	4	17	"	9	3	21	I	"
14	681	7	18	"	"	6	24	I	"
15	"	12	6	"	"	10	18	I	"
16	"	12	20	"	"	11	2	I	"
17	682	3	6	"	10	1	19	I	"
18	"	4	22	"	10	3	7	I	"
19	"	8	28	"	"	7	17	I	"
20	"	9	22	"	"	8	12	III	"
21	"	"	27	"	"	"	17	I	"
22	684	11	29	"	12	10	14	III	Iyo, Tosa, Izu, Yamato etc.
23	686	1	12	"	13	12	10	I	Yamato.
24	"	2	20	Shucho.	1	1	19	I	"
25	687	12	29	Jito-Tenno.	1	11	17	I	"
26	701	5	12	Taiho	1	3	26	III	Tanba.
27	712	7	19	Wado	5	6	7	I	Yamato.
28	715	7	4	Reiki	8	5	25	III	Totomi.
29	"	"	5	"	"	"	26	III?	Mikawa.

¹ A month in old Japanese calendar marked with an asterisk (*) is the extra or intercalary month of the same name.

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
30	715	8	17	Reiki.	8	7	10	I	Yamato.
31	716	2	5	"	2	1	4	I	"
32	719	4	24	Yoro.	3	3	26	I	"
33	720	"	1	"	4	2	15	I	"
34	721	2	28	"	5	1	24	I	"
35	"	3	1	"	"	1	25	I	"
36	"	3	13	"	"	2	7	I	"
37	722	1	24	"	"	12	29	I	"
38	732	8	14	Tenpei.	4	7	15	I	"
39	733	1	16	"	"	12	22	I	"
40	734	5	18	"	6	4	7	III	Whole Japan.
41	"	10	29	"	"	9	24	III	Yamato.
42	737	11	19	"	9	10	19	I	"
43	738	10	27	"	10	9	6	I	"
44	742	5	7	"	14	3	24	I	Yamashiro.
45	"	11	28	"	"	10	23	III	Osuni.
46	743	1	20	"	"	12	16	I	Yamashiro.
47	"	8	15	"	15	7	17	I	"
48	744	6	30	"	16	5	12	III ²	Higo.
49	745	6	5	"	17	4	27	III	Mino.
50	"	"	9	"	"	5	1	I	Settsu.
51	"	"	10	"	"	"	2	I	"
52	"	"	11	"	"	"	3	I	"
53	"	"	12	"	"	"	4	I	"
54	"	"	13	"	"	"	5	I	"
55	"	"	14	"	"	"	6	I	"
56	"	"	15	"	"	"	7	I	"
57	"	"	16	"	"	"	8	I	"
58	"	"	17	"	"	"	9	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
59	745	6	18	Tenpei.	17	5	10	I	Settsu.
60	"	"	24	"	"	"	16	I	"
61	"	"	26	"	"	"	18	I	"
62	"	8	22	"	"	7	17	I	"
63	"	"	23	"	"	"	18	I	"
64	"	9	28	"	"	8	24	I	"
65	"	10	3	"	"	"	29	I	"
66	"	10	5	"	"	9	2	I	"
67	746	2	12	"	18	1	14	I	Yamato.
68	"	"	27	"	"	1	29	I	"
69	"	"	28	"	"	1	30	I	"
70	"	7	2	"	"	6	5	I	"
71	"	10	6	"	"	9	13	I	"
72	"	11	4	"	"	9*	13	I	"
73	747	6	28	"	19	5	12	I	"
74	752	2	4	Tenpei-shoho.	4	1	11	I	"
75	"	11	15	"	"	10	1	I	"
76	"	"	16	"	"	"	2	I	"
77	762	6	9	Tenpei-hoji.	6	5	9	III	Mino, Hida, Shinano.
78	766	7	20	Tenpei-jingo.	2	6	5	III	Osami.
79	773	3	18	Hoki.	4	2	17	I	Yamato.
80	"	"	31	"	"	"	30	I	"
81	"	9	24	"	"	8	29	I	"
82	"	10	25	"	"	10	1	I	"
83	"	"	28	"	"	"	4	I	"
84	775	3	17	"	6	2	8	I	"
85	"	6	10	"	"	5	4	I	"
86	"	11	7	"	"	10	6	I	"
87	776	"	28	"	7	10	9	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
88	776	12	21	Hoki.	7	11	2	I	Yamato.
89	778	6	25	"	9	5	22	I	"
90	"	"	29	"	"	"	26	I	"
91	781	4	8	Ten-o.	1	3	6	I	"
92	"	6	5	"	"	5	4	I	"
93	"	"	14	"	"	"	13	I	"
94	"	7	11	"	"	6	12	I	"
95	"	"	21	"	"	"	22	I	"
96	781	11	4	"	"	10	10	I	"
97	"	11	26	"	"	11	3	I	"
98	"	12	20	"	"	"	27	I	"
99	782	1	4	"	"	12	12	I	"
100	"	"	16	"	"	"	24	I	"
101	"	3	5	Yen-ryaku.	1	1*	13	I	"
102	"	"	7	"	"	"*	15	I	"
103	"	4	10	"	"	2	19	I	"
104	"	8	1	"	"	6	14	I	"
105	"	9	11	"	"	7	25	I	"
106	783	2	1	"	2	1	23	I	"
107	785	7	12	"	4	5	27	I	Yamashiro.
108	"	10	14	"	"	9	3	I	"
109	786	3	7	"	5	1	28	I	"
110	790	12	29	"	9	11	15	I	"
111	791	1	25	"	"	12	13	I	"
112	792	2	27	"	11	1	27	I	"
113	793	10	13	"	12	8	30	I	"
114	"	11	26	"	"	10	15	I	"
115	794	2	23	"	13	1	15	I	"
116	"	7	18	"	"	6	13	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
117	794	10	3	Yen-ryaku.	13	9	1	I	Yamashiro.
118	"	"	4	"	"	"	2	I	"
119	797	9	13	"	16	8	14	I	Kyoto.
120	798	5	4	"	17	4	10	I	"
121	799	12	9	"	18	11	4	I	"
122	804	9	22	"	23	8	11	I	"
123	"	11	6	"	"	9	27	I	"
124	805	3	3	"	24	1	25	I	"
125	"	8	19	"	"	7	17	I	"
126	"	9	9	"	"	8	9	I	"
127	806	1	2	"	"	12	5	I	"
128	807	7	8	Taido.	2	5	25	II	"
129	810	8	3	Konin.	1	6	26	I	"
130	812	1	7	"	2	12	16	I	"
131	816	11	4	"	7	10	8	I	"
132	818	1	26	"	8	12	13	I	"
133	"	"	31	"	"	"	18	I	"
134	"	2	2	"	"	"	20	I	"
135	"	8		"	9	7		III	Sagami, Musashi, Shimosa, Hitachi, Kotsuke, Shimo- tsuke.
136	823	8	8	"	14	6	24	I	Kyoto.
137	"	9	23	"	"	8	12	I	"
138	824	1	17	"	"	12	9	I	"
139	825	2	12	Tencho.	2	1	17	I	"
140	"	3	23	"	"	2	26	I	"
141	826	1	18	"	3	1	5	I	"
142	"	"	27	"	"	"	14	I	"
143	"	2	5	"	"	"	23	I	"
144	"	4	8	"	"	2	24	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
145	826	5	26	Tencho.	3	4	12	I	Kyoto.
146	"	7	18	"	"	6	6	I	"
147	"	12	28	"	"	11	22	I	"
148	827	1	17	"	"	12	13	I	"
149	"	5	20	"	4	4	17	I	"
150	"	8	11	"	"	7	12	III	Kyoto, after-shocks continued for one year.
151	828	7	22	"	5	6	3	I	"
152	"	"	24	"	"	"	5	I	"
153	"	8	13	"	"	"	25	I	"
154	"	11	19	"	"	10	5	I	"
155	"	12	6	"	"	10	22	II	"
156	"	12	7	"	"	"	23	I	"
157	829	1	8	"	"	11	25	I	"
158	"	4	11	"	6	3	1	II	"
159	"	10	11	"	"	9	6	I	"
160	"	11	24	"	"	10	21	I	"
161	830	2	3	"	7	1	3	III	Dewa (Akita).
162	"	"	12	"	"	"	12	I	Kyoto.
163	"	"	22	"	"	"	22	I	"
164	"	9	8	"	"	8	14	I	"
165	"	11	27	"	"	11	5	I	"
166	831	5	10	"	8	3	21	I	"
167	"	7	30	"	"	6	14	I	"
168	"	10	9	"	"	8	26	I	"
169	832	2	19	"	9	1	10	I	"
170	"	3	7	"	"	"	27	I	"
171	"	6	12	"	"	5	7	I	"
172	"	10	15	"	"	9	14	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
173	832	10	19	Tencho.	9	9	18	I	Kyoto.
174	"	"	22	"	"	"	12	I	"
175	"	"	23	"	"	"	22	I	"
176	833	3	22	"	10	2	24	II	"
177	"	7	22	"	"	6	28	I	"
178	834	7	31	Showa.	1	6	18	I	"
179	835	4	7	"	2	3	2	I	"
180	836	4	5	"	3	3	12	I	"
181	"	6	11	"	"	5	20	II	"
182	"	8	2	"	"	6	13	I	"
183	837	7	28	"	4	6	19	I	"
184	"	8	24	"	"	7	16	I	"
185	"	10	8	"	"	9	2	I	"
186	838	6	27	"	5	5	28	I	"
187	"	7	1	"	"	6	2	I	"
188	839	5	27	"	6	4	7	I	"
189	"	8	24	"	"	7	8	I	"
190	840	2	23	"	7	1	13	I	"
191	"	11	13	"	"	10	12	I	"
192	841	3	13	"	8	2	13	III	Shinano.
193	"	7	30	"	"	7	5	III	Izu.
194	842	3	22	"	9	2	3	I	Kyoto.
195	"	4	17	"	"	2	29	I	"
196	"	5	4	"	"	3	16	I	"
197	"	7	30	"	"	6	15	I	"
198	"	9	25	"	"	8	14	I	"
199	"	12	23	"	"	11	14	I	"
200	843	1	20	"	"	12	12	I	"
201	"	6	18	"	10	5	13	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
202	843	12	7	Showa.	10	11	9	I	Kyoto.
203	845	9	12	„	12	8	4	I	„
204	„	10	3	„	„	„	25	I	„
205	846	3	31	„	13	2	27	I	„
206	848	4	3	Kasho.	1	2	22	I	„
207	„	4	18	„	„	3	8	I	„
208	„	5	8	„	„	„	28	I	„
209	„	„	13	„	„	4	3	I	„
210	„	6	30	„	„	5	22	I	„
211	„	7	31	„	„	6	24	I	„
212	„	8	1	„	„	„	25	I	„
213	„	11	10	„	„	10	7	I	„
214	„	„	23	„	„	„	20	I	„
215	849	1	3	„	„	12	2	I	„
216	„	4	10	„	2	3	10	I	„
217	„	5	12	„	„	4	13	I	„
218	„	7	30	„	„	7	4	I	„
219	„	8	14	„	„	„	19	I	„
220	850	2	22	„	3	1	3	I	„
221	„	3	14	„	„	„	23	I	„
222	„	4	11	„	„	2	21	I	„
223	„	4	24	„	„	3	5	I	„
224	„	5	10	„	„	„	21	I	„
225	„	„	24	„	3	4	6	I	„
226	„	6	2	„	„	„	15	I	„
227	„	10	9	„	„	8	26	I	„
228	„	11	27	„	„	10	16	III	Dewa.
229	851	2	20	Ninju.	1	1	12	I	Kyoto.
230	„	3	12	„	„	2	2	I	„

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
231	851	4	23	Ninju.	1	3	15	I	Kyoto.
232	"	5	12	"	"	4	4	I	"
233	"	6	6	"	"	"	29	I	"
234	"	"	17	"	"	5	11	I	"
235	"	"	30	"	"	"	24	I	"
236	"	8	12	"	"	7	8	I	"
237	"	11	5	"	"	10	5	I	"
238	"	"	13	"	"	"	13	I	"
239	"	12	21	"	"	11	21	I	"
240	852	3	1	"	2	2	3	I	"
241	"	4	8	"	"	3	12	I	"
242	"	5	14	"	"	4	18	I	"
243	"	6	27	"	"	6	3	I	"
344	"	9	20	"	"	8	28	I	"
245	"	10	12	"	"	8*	22	I	"
246	"	"	28	"	"	9	8	I	"
247	"	11	23	"	"	10	5	I	"
248	"	12	6	"	"	"	18	I	"
249	"	"	25	"	"	11	7	I	"
250	853	2	28	"	3	1	13	I	"
251	"	3	2	"	"	"	15	I	"
252	"	5	3	"	"	3	18	I	"
253	"	"	17	"	"	4	2	I	"
254	"	8	16	"	"	7	4	I	"
255	"	"	27	"	"	"	15	I	"
256	"	9	3	"	"	"	22	I	"
257	"	10	4	"	"	8	24	I	"
258	"	11	10	"	"	10	2	I	"
259	"	12	20	"	"	11	13	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
260	854	6	19	Saiko.	1	5	17	I	Kyoto.
261	"	8	1	"	"	6	30	I	"
262	"	"	31	"	"	8	1	I	"
263	"	10	19	"	"	9	20	I	"
264	"	11	30	"	"	11	3	I	"
265	"	12	19	"	"	"	22	I	"
266	855	4	25	"	2	4	2	I	"
267	"	7	1	"	"	5	10	I	"
268	"	"	2	"	"	"	11	I	"
269	"	8	11	"	"	6	21	I	"
270	"	"	15	"	"	"	25	I	"
271	"	9	14	"	"	7	26	I	"
272	"	"	19	"	"	8	1	I	"
273	"	"	20	"	"	"	2	I	"
274	"	10	13	"	"	"	25	I	"
275	"	"	27	"	"	9	9	I	"
276	"	"	28	"	"	"	10	I	"
277	"	11	6	"	"	"	19	I	"
278	"	"	7	"	"	"	20	I	"
279	"	"	16	"	"	"	29	I	"
280	"	"	19	"	"	10	3	I	"
281	"	12	31	"	"	11	15	I	"
282	856	1	27	"	"	12	12	I	"
283	"	4	2	"	3	2	20	I	"
284	"	"	3	"	"	"	21	I	"
285	"	"		"	"	3		III	Kyoto, several shocks in this month.
286	"	5	12	"	"	4	1	I	"
287	"	"	13	"	"	"	2	I	"
288	"	7	10	"	"	6	1	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
289	856	7	11	Saiko.	3	6	2	I	Kyoto.
290	"	8	23	"	"	7	16	I	"
291	"	"	25	"	"	"	18	I	"
292	"	9	4	"	"	"	28	I	"
293	"	10	27	"	"	9	21	I	"
294	"	"	31	"	"	"	25	I	"
295	"	11	6	"	"	10	1	I	"
296	"	"	23	"	"	"	18	I	"
297	"	"	29	"	"	"	24	I	"
298	"	"	30	"	"	"	25	I	"
299	"	12	5	"	"	11	1	I	"
300	"	"	6	"	"	"	2	I	"
301	"	"	18	"	"	"	14	I	"
302	857	1	13	"	"	12	10	I	"
303	"	3	5	Ten-an.	1	2	2	I	"
304	"	"	10	"	"	"	7	I	"
305	"	"	17	"	"	"	14	I	"
306	"	"	19	"	"	"	16	I	"
307	"	"	24	"	"	"	21	I	"
308	"	5	21	"	"	4	20	I	"
309	"	6	10	"	"	5	11	I	"
310	"	"	19	"	"	"	20	I	"
311	"	8	5	"	"	7	8	I	"
312	"	"	21	"	"	"	24	I	"
313	"	10	20	"	"	9	25	I	"
314	"	11	3	"	"	10	9	I	"
315	858	5	13	"	2	3	23	I	"
316	"	6	12	"	"	4	23	I	"
317	"	7	14	"	"	5	26	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
318	858	7	30	Ten-an.	2	6	13	I	Kyoto.
319	"	11	5	"	"	9	22	I	"
320	"	12	21	"	"	11	9	I	"
321	859	1	24	"	2	12	13	I	"
322	"	9	1	Jokan.	1	7	27	I	"
323	"	"	12	"	"	8	8	I	"
324	"	10	17	"	"	9	14	I	"
325	"	12	1	"	"	10	29	II	"
326	"	"	13	"	"	11	12	I	"
327	"	5	20	"	2	4	22	I	"
328	"	6	1	"	"	5	5	I	"
329	"	"	14	"	"	"	18	I	"
330	"	7	13	"	"	6	17	I	"
331	"	"	18	"	"	"	22	I	"
332	"	"	21	"	"	"	25	I	"
333	"	8	8	"	"	7	14	I	"
334	"	"	11	"	"	"	17	I	"
335	"	"	18	"	"	"	24	I	"
336	"	9	29	"	"	9	7	I	"
337	"	10	28	"	"	10	7	I	"
338	860	11	21	"	"	"*	1	I	"
339	"	12	13	"	"	"*	23	I	"
340	861	1	22	"	"	12	4	I	"
341	"	2	26	"	3	1	9	I	"
342	"	5	24	"	"	4	7	I	"
343	"	6	28	"	"	5	13	I	"
344	"	7	4	"	"	"	19	I	"
345	"	"	5	"	"	"	20	I	"
346	"	"	7	"	"	6	23	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
347	861	9	28	Jokan.	3	8	17	I	Kyoto.
348	862	2	17	"	4	1	11	I	"
349	"	3	3	"	"	"	25	I	"
350	"	"	25	"	"	2	17	I	"
351	"	4	2	"	"	"	25	I	"
352	"	"	17	"	"	3	11	I	"
353	"	5	4	"	4	3	28	I	"
354	"	6	20	"	"	5	16	I	"
355	"	7	20	"	"	6	16	I	"
356	"	8	24	"	"	7	21	I	"
357	"	"	30	"	"	"	27	I	"
358	"	10	16	"	"	9	15	I	"
359	"	"	22	"	"	"	21	I	"
360	"	"	25	"	"	"	24	I	"
361	"	"	30	"	"	"	29	I	"
362	"	11	8	"	"	10	9	I	"
363	"	"	27	"	"	"	28	I	"
364	"	12	1	"	"	11	3	II	"
365	863	1	13	"	"	12	16	I	"
366	"	"	24	"	"	"	27	I	"
367	"	3	1	"	5	2	4	I	"
368	"	5	9	"	"	4	14	I	"
369	"	7	10	"	"	6	17	II	Etchu and Echigo, after-shocks continued for several days.
370	"	8	1	"	"	" *	9	I	Kyoto.
371	"	9	28	"	"	8	8	I	"
372	"	10	27	"	"	9	8	I	"
373	"	12	31	"	"	11	13	I	"
374	864	8	26	"	6	7	17	III	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
375	864	10	12	Jokan.	6	9	4	I	Kyoto.
376	"	11	3	"	"	"	26	I	"
377	"	"	9	"	"	10	3	I	"
378	"	"	15	"	"	"	9	I	"
379	"	"	18	"	"	"	12	II	"
380	865	2	17	"	7	1	14	I	"
381	"	3	4	"	"	"	29	I	"
382	"	4	25	"	"	3	22	I	"
383	"	5	14	"	"	4	12	I	"
384	"	10	21	"	"	9	24	I	"
385	"	11	26	"	"	11	1	I	"
386	"	12	9	"	"	"	14	I	"
387	"	"	27	"	"	12	2	I	"
388	866	2	18	"	8	1	25	I	"
389	"	4	27	"	"	3*	5	I	"
390	"	7	26	"	"	6	7	I	"
391	"	8	4	"	"	"	16	I	"
392	"	10	1	"	"	8	15	I	"
393	"	12	3	"	"	10	19	I	"
394	"	"	21	"	"	11	7	I	"
395	867	1	23	"	"	12	10	I	"
396	"	3	4	"	9	1	20	I	Bungo, the Tsurumi-san erupted.
397	"	"	11	"	"	"	27	I	Kyoto.
398	"	"	14	"	"	2	1	I	"
399	"	6	21	"	"	5	12	I	Higo, the Aso-san erupted.
400	"	"	22	"	"	"	13	I	Kyoto.
401	"	8	7	"	"	6	30	I	"
402	"	9	1	"	"	7	25	I	"
403	"	"	19	"	"	8	14	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	District.
	Year	Month	Day	Period	Year	Month	Day		
404	867	9	30	Jokan.	9	8	25	I	Kyoto.
405	"	10	11	"	"	9	6	I	"
406	"	11	8	"	"	10	5	I	"
407	868	5	13	"	10	4	13	I	"
408	"	"	28	"	"	"	28	I	"
409	"	6	18	"	"	5	19	I	"
410	"	8	3	"	"	7	8	III	Kyoto and Harima, after-shocks continued for three months.
411	"	11	19	"	"	10	27	I	Kyoto.
412	"	12	18	"	"	11	27	I	"
413	"	"	22	"	"	12	1	I	"
414	"	"	31	"	"	"	10	I	"
415	869	1	6	"	"	"	16	I	"
416	"	3	24	"	11	2	4	I	"
417	"	4	18	"	"	"	29	I	"
418	"	7	13	"	"	5	26	III	Mitsu.
419	"	8	22	"	"	7	7	I	Kyoto.
420	"	11	6	"	"	9	25	I	"
421	870	1	22	"	"	12	13	I	"
422	"	2	1	"	"	"	23	I	"
423	"	"	24	"	12	1	16	I	"
424	"	4	15	"	"	3	7	I	"
425	"	6	12	"	"	5	6	I	"
426	"	11	7	"	"	10	7	I	"
427	"	12	25	"	"	11	25	I	"
428	871	8	3	"	13	7	10	I	"
429	"	8	18	"	"	"	25	I	"
430	"	"	30	"	"	8	7	I	"
431	"	9	9	"	"	"	17	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	District.
	Year	Month	Day	Period	Year	Month	Day		
442	871	10	23	Jokan.	13	9	2	I	Kyoto.
433	"	11	18	"	"	"	28	I	"
434	872	1	10	"	"	11	22	I	"
435	"	"	17	"	"	"	29	I	"
436	"	3	9	"	14	1	22	I	"
437	"	5	12	"	"	3	27	I	"
438	"	7	29	"	"	6	16	I	"
439	"	8	6	"	"	"	24	I	"
440	"	"	11	"	"	"	29	I	"
441	"	9	7	"	"	7	27	I	"
442	"	10	10	"	"	9	1	I	"
443	"	11	8	"	"	"	30	I	"
444	"	"	10	"	"	10	2	I	"
445	"	12	24	"	"	11	17	I	"
446	"	"	30	"	"	"	23	I	"
447	873	1	4	"	"	"	28	I	"
448	"	"	9	"	"	12	3	I	"
449	"	2	25	"	15	1	20	I	"
450	"	3	8	"	"	2	2	I	"
451	"	"	24	"	"	"	18	I	"
452	"	4	20	"	"	3	16	I	"
453	"	5	18	"	"	4	14	II	"
454	"	"	22	"	"	"	18	I	"
455	"	"	28	"	"	"	24	I	"
456	"	6	3	"	"	5	1	I	"
457	"	"	13	"	"	"	11	I	"
458	"	7	16	"	"	6	14	I	"
459	"	10	12	"	"	9	13	I	"
460	"	11	26	"	"	10	29	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
461	874	3	10	Jokan.	16	2	14	I	Kyoto.
462	"	4	10	"	"	3	16	I	"
463	"	"	15	"	"	"	21	I	"
464	"	"	19	"	"	"	25	I	"
465	"	"	24	"	"	4	1	I	"
466	"	6	10	"	"	4*	18	I	"
467	"	"	15	"	"	"	23	I	"
468	"	"	25	"	"	5	4	I	"
469	"	8	10	"	"	6	21	I	"
470	"	"	21	"	"	7	2	I	"
471	"	11	3	"	"	9	17	I	"
472	"	12	29	"	"	11	13	I	"
473	875	2	12	"	"	12	29	II	"
474	"	3	27	"	17	2	12	I	"
475	"	4	2	"	"	"	18	I	"
476	"	"	13	"	"	"	29	I	"
477	"	"	22	"	"	3	9	I	"
478	"	"	27	"	"	"	14	I	"
479	"	7	20	"	"	6	10	I	"
480	"	8	21	"	"	7	13	I	"
481	"	9	17	"	"	8	10	I	"
482	"	"	23	"	"	"	16	I	"
483	876	6	13	"	18	5	14	I	"
484	"	"	14	"	"	"	15	I	"
485	"	"	20	"	"	"	21	I	"
486	"	7	16	"	"	6	18	I	"
487	"	8	25	"	"	7	28	I	"
488	"	12	2	"	"	11	9	I	"
489	877	5	1	Genkei.	1	3	11	II	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
490	877	7	1	Genkei.	1	5	13	I	Kyoto.
491	"	8	30	"	"	7	14	I	"
492	"	11	29	"	"	10	17	II	"
493	"	"	30	"	"	"	18	I	"
494	878	4	9	"	2	2	29	I	"
495	"	"	19	"	"	3	9	I	"
496	"	8	9	"	"	7	4	I	"
497	"	"	16	"	"	"	11	I	"
498	"	"	30	"	"	"	25	I	"
499	"	11	1	"	"	9	29	III	Sagami, Musashi.
500	"	"	11	"	"	10	9	I	Kyoto.
501	879	4	6	"	3	3	7	I	"
502	"	"	7	"	"	"	8	I	"
503	"	"	21	"	"	"	22	I	"
504	"	"	28	"	"	"	29	I	"
505	"	"	30	"	"	4	2	I	"
506	"	5	5	"	"	"	7	I	"
507	"	6	12	"	"	5	15	I	"
508	"	7	13	"	"	6	16	I	"
509	"	8	14	"	"	7	19	I	"
510	"	"	26	"	"	8	2	I	"
511	"	9	7	"	"	"	14	I	"
512	880	4	11	"	4	2	24	I	"
513	"	"	15	"	"	"	28	I	"
514	"	5	18	"	"	4	2	II	"
515	"	"	21	"	"	"	5	I	"
516	"	"	26	"	"	"	10	I	"
517	"	6	20	"	"	5	5	I	"
518	"	8	30	"	"	7	17	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
519	880	11	10	Genkei.	4	10	1	I	Kyoto.
520	"	"	11	"	"	"	2	I	"
521	"	"	12	"	"	"	3	I	"
522	"	"	23	"	"	"	14	III	Izumo.
523	881	1	3	"	"	11	25	I	Kyoto.
524	"	"	11	"	"	12	4	II	"
525	"	"	13	"	"	"	6	III	Kyoto, after-shocks continued for one month.
526	"	2	12	"	5	1	6	I	Kyoto.
527	"	"	17	"	"	"	11	I	"
528	"	"	18	"	"	"	12	I	"
529	"	"	20	"	"	"	14	I	"
530	"	"	22	"	"	"	16	I	"
531	"	3	10	"	"	2	3	I	"
532	"	"	30	"	"	"	23	I	"
533	"	5	8	"	"	4	3	I	"
534	"	"	9	"	"	"	4	I	"
535	"	6	17	"	"	5	13	I	"
536	"	7	28	"	"	6	25	I	"
537	"	10	19	"	"	9	19	I	"
538	"	"	20	"	2	"	20	I	"
539	"	"	21	"	4	"	21	I	"
540	"	11	4	"	"	10	5	I	"
541	882	1	5	"	"	12	8	I	"
542	"	4	19	"	6	3	24	I	"
543	"	7	12	"	"	6	19	I	"
544	"	10	23	"	"	9	4	I	"
545	883	1	2	"	6	11	16	I	"
546	"	7	14	"	7	6	3	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
547	883	8	8	Genkei.	7	6	28	I	Kyoto.
548	"	11	6	"	"	10	29	I	"
549	884	5	16	"	8	4	14	I	"
550	"	"	18	"	"	"	16	I	"
551	"	7	29	"	"	6	29	I	"
552	"	12	1	"	"	11	6	I	"
553	855	3	10	Ninwa.	1	2	16	I	"
554	"	7	16	"	"	5	26	I	"
555	"	9	5	"	"	7	19	I	"
556	"	10	28	"	"	9	13	I	"
557	"	"	29	"	"	"	14	I	"
558	886	2	1	"	"	12	20	I	"
559	"	5	2	"	2	3	21	I	"
560	"	"	24	"	"	4	13	II	"
561	"	7	3	"	"	5	24	I	Awa, accompanied by falling of ashes.
562	"	"	24	"	"	6	15	II	Kyoto.
563	"	10	15	"	"	9	11	I	"
564	887	6	28	"	3	5	29	I	"
565	"	7	29	"	"	7	2	I	"
566	"	8	2	"	"	"	6	I	"
567	"	"	26	"	"	"	30	III	Kyoto and whole Japan, especially Settsu and Shinano, with sea-waves along the coast of Settsu; the after-shocks continued for one month.
568	"	10	29	"	"	10	5	I	Kyoto.
569	898	8	22	Shotai.	1	7	27	II	"
570	899	10	19	"	2	9	7	I	"
571	902	9	3	Yenki.	2	7	24	I	"
572	904	12	26	"	4	11	12	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
573	906	4	2	Yenki.	6	3	1	I	Kyoto.
574	909	3	6	"	9	2	7	I	"
575	911	2	19	"	11	1	13	I	"
576	912	2	6	"	12	1	11	I	"
577	"	4	16	"	"	3	21	I	"
578	916	8	5	"	16	6	29	I	"
579	925	1	19	Yencho.	2	12	17	I	"
580	926	2	20	"	4	1	1	I	"
581	"	6	7	"	"	4	19	I	"
582	928	4	6	"	6	3	8	I	"
583	"	5	14	"	"	4	17	I	"
584	"	6	25	"	"	6	1	I	"
585	931	2	7	Shohei.	1	1	12	I	"
586	"	3	28	"	"	3	2	I	"
587	932	3	9	"	2	1	25	I	"
588	"	5	4	"	"	3	21	I	"
589	"	"	14	"	"	4	1	I	"
590	"	8	6	"	"	6	26	I	"
591	934	7	16	"	4	5	27	III	Kyoto, after-shocks continued for two days.
592	"	"	22	"	"	6	3	I	"
593	"	12	3	"	"	10	19	I	"
594	935	3	10	"	5	1	28	I	"
595	"	"	31	"	"	2	19	I	"
596	"	4	1	"	"	"	20	I	"
597	"	5	17	"	"	4	7	I	"
598	"	"	25	"	"	"	15	II	"
599	938	5	22	Tengyo.	1	4	15	III	Yamashiro and Yama- to, after-shocks con- tinued for two months.

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
600	938	11	20	Tengyo.	1	10	21	I	Kyoto.
601	939	2	7	"	2	1	11	I	"
602	"	3	3	"	"	2	5	I	"
603	"	"	19	"	"	"	21	I	"
604	"	"	27	"	"	"	29	I	"
605	"	4	1	"	"	3	4	I	"
606	"	"	3	"	"	"	6	I	"
607	"	"	8	"	"	"	11	I	"
608	"	"	10	"	"	"	13	I	"
609	"	4	20	"	"	3	23	I	"
610	"	5	26	"	"	4	30	I	"
611	"	6	5	"	"	5	10	I	"
612	"	"	22	"	"	"	27	I	"
613	"	"	27	"	"	6	3	I	"
614	"	7	13	"	"	"	19	I	"
615	"	"	17	"	"	"	23	I	"
616	"	8	8	"	"	7	16	I	"
617	940	4	25	"	3	3	10	I	"
618	"	5	1	"	"	"	16	I	"
619	942	4	9	"	5	3	16	I	"
620	"	"	10	"	"	"	17	I	"
621	"	"	11	"	"	"	18	I	"
622	"	5	10	"	"	3 ²²	18	I	"
623	943	6	11	"	6	5	1	I	"
624	945	10	25	"	8	9	12	I	"
625	"	"	27	"	"	"	14	I	"
626	946	2	11	"	9	1	2	I	"
627	947	3	3	Tenreki.	1	2	3	I	"
628	949	"	16	"	3	2	9	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
629	958	3		Tentoku.	2			I	Kyoto.
630	965	10	22	Koho.	2	9	21	II	Kyoto, after-shocks continued for two days.
631	"	11	1	"	"	10	1	I	Kyoto.
632	968	5	11	Anwa.	1	4	7	I	"
633	"	9	4	"	"	8	4	I	"
634	971	5	8	Tenroku.	2	4	6	I	"
635	"	8	4	"	"	7	6	I	"
636	972	4	5	"	3	2*	14	III	"
637	973	5	4	Tenyen.	1	3	24	I	"
638	"	10	30	"	"	9	27	II	"
639	976	5	17	Jogen.	1	4	11	II	"
640	"	7	22	"	"	6	18	III	Yamashiro and Omi, after-shocks continued for four months.
641	977	3	1	"	2	2	4	I	Kyoto.
642	"	"	6	"	"	"	9	II	"
643	978	12	27	Tengen.	1	11	20	I	"
644	984	11	13	Yeikan.	2	10	13	I	"
645	"	12	8	"	"	11	8	II	"
646	986	8	18	Kanwa.	2	7	6	I	"
647	989			Yeiso.	1			I	"
648	990	11	20	Seireki.	1	10	25	I	"
649	994	12	4	"	5	"	24	II	"
650	996	4	27	Chotoku.	2	4	2	I	"
651	"	7	19	"	"	6	26	II	"
652	997	7	4	"	3	5	22	II	"
653	"	11	10	"	"	10	3	II	"
654	1027	4	18	Manju.	4	3	2	II	"
655	1032	4	23	Chogen.	5	3	5	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
656	1036	1	21	Chogen.	8	12	14	I	Kyoto.
657	1040	8	13	Chokin.	1	6	27	I	"
658	"	10	22	"	"	9	8	II	"
659	"	12	13	"	"	11	1	II	"
660	1041	8	25	"	2	7	20	III	"
661	1050	10	31	Yeisho.	5	10	7	I	"
662	1055	7	10	Tenki.	3	6	7	I	"
663	1060	7	24	Kohei.	3	6	18	I	"
664	1061	6	2	"	4	5	6	I	"
665	"	"	3	"	"	"	7	I	"
666	1063	4	5	"	6	2	28	I	"
667	"	"	7	"	"	"	30	I	"
668	"	"	18	"	"	3	11	I	"
669	1065	5	8	Jireki.	1	3	24	I	"
670	"	6	19	"	"	5	7	II	"
671	1066	5	10	"	2	4	8	I	"
672	1070	3	16	Yenkiu.	"	1	25	I	"
673	"	12	1	"	"	10	20	III	Kyoto, Nara.
674	"	"	4	"	"	"	23	I	Kyoto.
675	1071	1	1	"	"	11	21	I	"
676	1074	2	24	Shoho.	1	1	20	I	"
677	"	"	26	"	"	"	22	I	"
678	"	3	18	"	"	2	12	I	"
679	1076	1	22	"	3	1	9	I	"
680	1091	9	28	Kanji.	5	8	7	III	"
681	1092	12	17	"	6	11	10	II	"
682	1093	3	19	"	7	2	14	II	"
683	1096	12	17	Yeicho.	1	11	24	III	Kyoto, after-shocks continued for one month.

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
684	1097	8	20	Shotoku.	1	7	5	I	Kyoto.
685	"	"	21	"	"	"	6	II	"
686	"	9	20	"	"	8	6	I	"
687	"	"	22	"	"	"	8	I	"
688	1099	2	22	Kowa.	1	1	24	II	"
689	1103	6	5	"	5	4	22	II	"
690	"	"	7	"	"	"	24	I	"
691	"	"	14	"	"	5	1	I	"
692	1111	5	13	Tenyei.	2	3	27	I	"
693	1124	3	25	Tenji.	1	2*	1	II	"
694	1132	10	25	Chosho.	1	9	8	I	"
695	"	11	13	"	"	"	27	I	"
696	1133	1	25	"	"	12	6	I	"
697	"	10	5	"	2	8	28	I	"
698	1135	5	9	Hoyen.	1	3	18	II	"
699	1136	3	9	"	2	1	28	I	"
700	1137	8	10	"	3	7	15	III?	Kyoto, followed by minor shocks.
701	1142	4	15	Koji.	1	3	11	I	Kyoto.
702	"	9	16	"	"	8	18	I	"
703	1143	3	8	"	2	2	14	I	"
704	"	11	25	"	"	10	10	II	"
705	1144	1	3	"	2	11	20	I	"
706	"	"	7	"	"	"	24	II	"
707	"	"	9	"	"	"	26	I	"
708	"	5	27	Tenyo.	1	4	16	I	"
709	"	"	28	"	"	"	17	I	"
710	"	6	22	"	"	5	13	II	"
711	"	8	13	"	1	7	6	I	"
712	"	"	18	"	"	"	11	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
713	1145	1	8	Tenyo.	1	12	7	I	Kyoto.
714	"	3	15	Kin-an.	"	2	13	I	"
715	"	11	25	"	"	10 ³³	3	I	"
716	1153	10	17	Ninpei	3	9	21	II	"
717	1154	4	4	Kinju.	1	2	13	I	"
718	1155	9	10	"	2	8	5	II	"
719	1164	3	27	Chokan.	"	2	26	II	"
720	1165	7	20	Yeiman.	1	6	4	II	"
721	"	"	21	"	"	"	5	II	"
722	1169	2	4	Nin-an.	3	12	29	I	"
723	1177	11	26	Jisho.	1	10	27	III	"
724	1178	6	24	"	2	5	30	I	"
725	1179	7	11	"	3	5	28	I	"
726	"	"	14	"	"	6	1	I	"
727	"	"	30	"	"	"	17	I	"
728	"	12	14	"	"	11	7	II	"
729	1180	4	26	"	4	3	23	I	"
730	"	12	21	"	"	11	26	III	Kii.
731	1181	1	15	"	"	12	21	I	Kyoto.
732	1183	11	7	Juyei.	2	10	14	II	"
733	1184	2	12	"	"	12	22	II	"
734	"	11	26	Genreki.	1	10	15	I	Kamakura.
735	1185	7	25	Bunji.	1	6	20	II	Kamakura, Kyoto.
736	"	8	13	"	"	7	9	III	Kyoto, after-shocks continued for three months.
737	1187	11	20	"	3	10	12	III	Kyoto.
738	1191	4	8	Kenku.	2	3	6	II	Kamakura.
739	1195	"	30	"	6	3	12	I	"
740	1199	2	4	Seiji.	1	1	1	I	Kyoto.

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
741	1199	6	18	Seiji.	1	5	16	II	Kamakura.
742	1201	4	21	Kennin.	„	3	10	I	„
743	1202	2	29	Genkiu.	2	1	28	II	„
744	1203	2	15	„	„	12	24	I	„
745	1204	11	6	„	1	10	6	II	„
746	1205	1	25	Shogen.	„	12	27	II	Kyoto.
747	„	„	27	„	„	„	29	I	„
748	1207	5	14	„	1	4	9	II	„
749	1208	1	31	„	2	1	6	II	Kamakura.
750	„	9	8	„	„	7	20	I	„
751	1209	5	13	Kenreki.	3	4	1	I	„
752	1210	10	29	„	4	10	3	I	„
753	1211	2	19	„	1	1	27	II	„
754	„	7	4	Kenpo.	„	5	15	I	„
755	„	8	19	„	„	7	3	II	„
756	1213	1	31	„	1	1	1	I	„
757	„	6	18	„	„	5	21	III	„
758	„	8	2	„	„	7	7	II	„
759	„	9	22	„	„	8	29	I	„
760	„	10	9	„	„	9	17	II	„
761	1214	3	20	„	2	2	1	I	„
762	„	„	26	„	„	„	7	II	„
763	„	5	20	„	„	4	3	II	Kamakura, Kyoto.
764	„	11	2	„	„	9	22	II	Kamakura.
765	1215	9	23	„	3	8	21	I	„
766	„	„	24	„	„	„	22	I	„
767	„	10	7	„	„	9	6	III?	„
768	„	„	9	„	„	„	8	II?	„
769	„	10	12	„	„	9	11	II?	„

No	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
770	1220	2	24	Shokin.	2	1	12	I	Kamakura.
771	"	4	17	"	"	3	6	I	Kyoto.
772	1221	1	4	"	"	12	2	I	Kamakura.
773	"	3	1	"	3	1	29	I	"
774	"	10	25	"	"	10	2	I	"
775	1224	6	3	Gemin.	1	5	8	II	Kyoto.
776	1225	3	2	Karoku	1	4	15	I	Kamakura.
777	"	4	27	"	"	3	11	I	"
778	"	7	1	"	"	5	17	I	"
779	"	11	19	"	"	10	11	II	"
780	1226	5	4	"	2	3	29	I	"
781	"	"	31	"	"	4	27	II	"
782	"	7	30	"	"	6	26	I	"
783	"	"	31	"	"	"	27	I	"
784	"	8	1	"	"	"	28	I	"
785	"	"	2	"	"	7	1	I	"
786	"	9	1	"	"	8	1	II	"
787	"	11	4	"	"	10	6	I	"
788	1227	2	8	Antei.	1	1	14	I	"
789	"	4	1	"	"	3	7	III	"
790	"	"	9	"	"	"	15	I	"
791	"	6	5	"	"	4	13	I	"
792	"	"	18	"	"	"	26	I	"
793	"	7	3	"	"	5	11	I	"
794	"	10	21	"	"	9	3	II	"
795	"	12	22	"	"	11	6	III	"
796	1229	11		Kanki.	1	11		I	"
797	1234	10	17	Bnnreki.	1	9	16	II	Kyoto.
798	1235	4	5	Katei.	1	3	9	III	Kamakura.

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
799	1235	4	12	Katei.	1	3	16	II	Kamakura.
800	"	5	8	"	"	4	13	I	"
801	"	"	26	"	"	5	1	I	"
802	"	7	9	"	"	6	16	I	"
803	"	8	14	"	"	6*	22	I	"
804	"	10	21	"	"	9	1	II	Kyoto.
805	"	11	18	"	"	"	29	I	Kamakura.
806	1236	4	12	"	2	2	28	I	"
807	"	7	22	"	"	6	11	I	"
808	1237	5	10	"	3	4	7	I	"
809	"	7	1	"	"	6	1	II	Kyoto.
810	"	10	8	"	"	9	11	I	Kamakura.
811	"	"	20	"	"	"	23	I	"
812	"	"	21	"	"	"	24	I	"
813	1239	1	22	Rekinin.	1	12	9	I	"
814	"	12	15	Yen-o.	"	11	12	II	"
815	1240	2	14	Ninji.	"	1	13	II	"
816	"	5	18	"	"	4	18	I	"
817	1241	3	5	"	2	1	14	I	"
818	"	"	27	"	"	2	7	III	Kamakura and Kanto.
819	"	4	25	"	"	3	6	I	Kamakura.
820	"	5	4	"	"	"	15	I	"
821	"	"	22	"	"	4	3	III	Kamakura, accom- panied by sea-waves.
822	"	8	19	"	"	7	4	I	Kamakura.
823	"	11	24	"	"	10	13	I	"
824	1243	6	18	Kangen.	1	5	23	II	"
825	1244	7	27	"	2	6	14	I	"
826	"	8	13	"	"	7	2	I	Kyoto.
827	"	10	21	"	"	9	11	I	Kamakura.

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
828	1245	1	7	Kangen.	2	12	1	I	Kamakura.
829	"	2	23	"	3	1	18	I	"
830	"	"	25	"	"	"	20	I	Kyoto.
831	"	4	14	"	"	3	9	I	"
832	"	5	9	"	"	4	5	I	"
833	"	"	11	"	"	"	7	I	"
834	"	6	1	"	"	"	28	I	"
835	"	"	9	"	"	5	8	I	"
836	"	"	26	"	"	"	25	I	"
837	"	"	27	"	"	"	26	I	"
838	"	"	28	"	"	"	27	I	"
839	"	"	29	"	"	"	28	I	"
840	"	8	26	"	"	7	26	III	"
841	1246	1	16	"	"	12	20	II	Kamakura.
842	"	"	31	"	4	1	6	II	"
843	"	6	28	"	"	5	7	I	"
844	"	8	21	"	"	7	2	I	"
845	"	"	24	"	"	"	5	I	"
846	"	11	26	"	"	10	10	I	Kyoto.
847	1247	1	12	"	"	11	27	II	Kamakura.
848	"	"	20	"	"	12	5	II	Kyoto.
849	"	2	26	Kanji.	1	1	13	I	"
850	"	4	26	"	"	3	13	I	"
851	"	7	20	"	"	6	10	I	"
852	"	"	29	"	"	"	19	I	"
853	"	11	13	"	"	10	8	II	Kamakura.
854	"	12	31	"	"	11	26	II	"
855	1248	1	3	"	"	11	29	I	"
856	1250	8	24	Kencho.	2	7	18	III	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
857	1251	2	18	Kencho.	3	1	19	I	Kyoto.
858	"	10	10	"	"	9	17	I	"
859	"	12	14	"	"	10	23	I	Kamakura.
860	1252	6	22	"	4	5	7	I	"
861	1253	4	1	"	5	2	25	II	"
862	"	5	8	"	"	4	3	I	"
863	"	7	14	"	"	6	10	II	"
864	"	10	16	"	"	9	16	I	"
865	"	"	17	"	"	"	17	I	Kyoto.
866	1254	3	16	"	6	2	19	I	"
867	1255	1	5	"	"	11	18	II	Kamakura.
868	1257	7	8	Seika.	1	5	18	II	"
869	"	9	17	"	"	8	1	II	"
870	"	10	9	"	"	"	23	III	"
871	"	11	29	"	"	10	15	I	"
872	"	12	22	"	"	11	8	II	"
873	1258	6	2	"	2	4	22	I	"
874	1259	1	18	"	"	12	16	I	"
875	1260	5	13	Bun-o.	1	3	25	I	"
876	1263	7	6	Kocho.	3	5	19	I	"
877	1264	4	2	Bunyei.	1	2	27	I	Kyoto.
878	"	11	2	"	"	10	5	II	"
879	1265	2	9	"	2	1	15	I	Kamakura.
880	"	4	3	"	"	3	9	II	"
881	"	"	30	"	"	4	6	I	Kyoto.
882	1266	8	3	"	3	6	24	II	Kamakura.
883	1268	6	22	"	5	5	4	II	Kyoto.
884	1269	12	17	Bunyei.	6	11	16	I	Omi.
885	1273	4	5	"	10	3	9	III	Aizu.

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
886	1302	6	9	Kengen.	1	5	5	I	Kyoto.
887	1317	2	24	Bunpo.	1	1	5	II	"
888	1323	6	15	Genkyo.	3	5	3	I	Kamakura.
889	1325	12	5	Seichu.	2	10	21	III	Kinai provinces, strongly felt in Kyoto.
890									
891	1331	8	15	Genko.	1	7	3	III	Kii.
	"	"	19	"	"	"	7	III	Suruga.
892	1334	10	3	Kenbu.	1	8	27	II	Kyoto.
893	1335	1	16	"	"	12	13	II	"
894	1338	8	13	Yengen.	3	7	19	II	"
895	"	"	16	"	"	"	22	I	"
896	1339	10	15	"	4	9	4	II	"
897	"	12	16	"	"	11	7	I	Kamakura.
898	1340	3	3	Kokoku.	1	1	26	II	Kyoto.
899	1341	3	9	"	2	2	13	I	"
900	"	4	2	"	"	3	8	II	Kamakura.
901	"	11	3	"	"	9	16	II	Kyoto.
902	1342	7	26	"	3	6	15	I	"
903	1344	2	5	"	5	1	12	I	"
904	"	10	23	"	"	9	9	I	"
905	1345	7	14	"	6	6	7	I	"
906	"	"	26	"	"	"	19	I	Nara.
907	"	9	21	"	"	8	17	I	Kyoto.
908	1346	8	29	Shohei.	1	"	4	II	"
909	1347	1	13	"	"	11	23	I	"
910	"	"	22	"	"	12	2	I	"
911	"	3	5	"	2	1	15	I	"
912	"	3	10	"	"	"	20	II	"
913	"	6	23	"	"	5	6	I	"

No.	EUROPE A DATE.			JAPANESE DATE.				In tensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
914	1347	8	12	Shohei.	2	6	27	II	Kyoto.
915	"	10	11	"	"	8	28	I	"
916	"	11	4	"	"	9	23	I	"
917	"	"	14	"	"	10	3	I	"
918	"	"	15	"	"	"	4	I	"
919	"	12	26	"	"	11	16	I	"
920	"	"	30	"	"	"	20	I	"
921	"	"	31	"	"	"	21	I	"
922	1348	1	26	"	"	12	18	I	"
923	"	2	17	"	3	1	10	I	"
924	1349	5	8	"	4	4	13	I	"
925	"	"	9	"	"	"	14	I	"
926	"	9	10	"	"	7	19	II	"
927	1350	7	6	"	5	5	23	III	"
928	"	"	8	"	"	"	25	II	"
929	"	"	12	"	"	"	29	I	Kyoto, three shocks.
930	"	"	22	"	"	6	10	I	Kyoto.
931	"	"	23	"	"	"	11	I	"
932	"	8	1	"	"	"	20	I	"
933	"	"	3	"	"	"	22	II	"
934	"	"	6	"	"	"	25	I	Kyoto, two shocks.
935	"	"	13	"	"	7	2	I	Kyoto.
936	"	12	21	"	"	11	14	I	"
937	1351	3	25	"	6	2	19	II	"
938	"	4	21	"	"	3	17	I	"
939	"	5	15	"	"	4	11	I	"
940	"	10	9	"	"	9	11	I	"
941	"	12	16	"	6	11	19	I	Kyoto, two or three shocks.
942	1352	1	26	"	7	1	1	I	Kyoto.

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
943	1352	2	9	Shohei.	7	1	15	I	Kyoto.
944	"	4	8	"	"	2*	"	I	"
945	1355	12	30	"	10	11	18	I	"
946	1356	6	16	"	11	5	9	I	"
947	"	8	7	"	"	7	3	I	"
948	"	"	15	"	"	"	11	I	"
949	"	9	15	"	"	8	12	I	"
950	"	"	17	"	"	9	15	I	"
951	1357	2	15	"	12	1	18	I	"
952	"	7	26	"	"	7	1	I	"
953	"	8	11	"	"	"	17	I	"
954	"	9	9	"	"	7*	17	I	"
955	"	11	1	"	"	9	11	I	"
956	1358	3	14	"	13	1	26	I	"
957	"	"	20	"	"	2	2	I	"
958	"	"	29	"	"	"	11	I	"
959	"	5	3	"	"	3	17	I	"
960	"	5	30	"	"	4	14	I	"
961	"	7	9	"	"	5	24	II	"
962	"	"	16	"	"	6	2	I	"
963	"	8	28	"	"	7	15	I	"
964	"	10	15	"	"	9	4	II	"
965	"	12	27	"	"	11	18	I	"
966	1359	7	5	"	14	6	2	I	"
967	"	11	17	"	"	10	18	I	"
968	1360	2	26	"	15	2	1	I	"
969	"	3	3	"	"	"	7	I	"
970	1361	"	8	Jokan.	16	1	23	I	"
971	"	7	31	"	"	6	21	II	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
972	"	8	1	Jokan.	16	6	22	III	Kyoto, Kii, Yamato and Settsu, with sea-waves along the coast of Awa (in Shikoku); strongly felt in Kyoto.
973	"	"	3	"	"	"	24	III	Kyoto, Kawachi, Settsu, Yamato, Kii and Awa, with sea-waves along the coasts of Settsu and Awa (in Shikoku); strongly felt in Kyoto, where after-shocks continued for several days.
974	"	"	10	"	"	7	1	I	Kyoto.
975	"	"	13	"	"	"	4	II	"
976	"	"	20	"	"	"	11	III	Yamato.
977	"	9	8	"	"	8	1	I	Kyoto.
978	"	12	19	"	"	11	14	II	"
979	1362	6	17	"	17	5	17	II	"
980	"	9	2	"	"	8	5	I	"
981	"	10	30	"	"	10	4	I	"
982	"	11	6	"	"	"	11	I	"
983	"	"	19	"	"	"	24	I	"
984	"	12	13	"	"	11	19	I	"
985	"	"	16	"	"	"	22	I	"
986	"	"	22	"	"	"	28	I	"
987	1362	12	26	"	"	12	2	I	Kyoto, two shocks.
988	"	"	29	"	"	"	5	II	Kyoto.
989	"	"	30	"	"	"	6	I	"
990	1363	3	8	"	18	1*	14	I	Kyoto, two shocks.
991	"	"	9	"	"	"	15	I	Kyoto.
992	"	"	27	"	"	2	4	II	"
993	"	4	2	"	"	"	10	I	Kyoto, two or three shocks.
994	"	"	10	"	"	"	18	II	Kyoto.

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
995	1363	8	31	Shohei.	18	7	14	II	Kyoto.
996	"	9	19	"	"	8	4	II	"
997	"	12	22	"	"	11	9	II	"
998	1364	10	14	"	19	9	11	I	"
999	1367	2	16	"	22	1	9	II	"
1000	"	3	11	"	"	2	2	I	"
1001	"	"	25	"	"	"	16	II	"
1002	"	6	19	"	"	5	14	I	"
1003	"	7	24	"	"	6	19	I	"
1004	"	"	30	"	"	"	25	I	"
1005	"	9	14	"	"	8	12	I	"
1006	"	"	23	"	"	"	21	II	"
1007	1368	2	15	"	23	1	18	I	"
1008	"	7	29	"	"	6 ³⁰	6	I	"
1009	1369	9	7	"	24	7	28	II	"
1010	1370	9	26	Kentoku.	1	8	18	I	Kamakura.
1011	1371	4	13	"	2	3	19	II	Kyoto.
1012	"	10	13	"	"	8	26	I	"
1013	"	"	14	"	"	"	27	II	"
1014	1372	8	5	Bunchn.	1	6	17	I	"
1015	1373	1	26	"	"	12	24	I	"
1016	"	3	4	"	2	2	2	I	"
1017	"	5	2	"	"	4	1	II	"
1018	"	"	13	"	"	"	12	I	"
1019	"	9	15	"	"	8	20	I	"
1020	"	12	14	"	"	10 ³⁰	22	II	"
1021	1375	5	23	Tenju.	1	4	14	III	Aizu.
1022	"	7	18	"	"	6	11	I	Kyoto.
1023	"	"	30	"	"	"	23	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1024	1376	5	22	Tenju.	2	4	25	II	Kyoto.
1025	1378	11	27	"	4	10	29	II	"
1026	1379	11	26	"	5	"	9	II	"
1027	1380	5	29	"	6	4	17	I	"
1028	1381	3	20	Kowa.	1	2	16	I	"
1029	"	5	22	"	"	4	20	I	"
1030	"	6	29	"	"	5	29	I	"
1031	1383	5	29	"	3	4	19	I	"
1032	"	6	3	"	"	"	24	II	"
1033	"	"	5	"	"	"	26	I	"
1034	"	"	8	"	"	"	29	I	"
1035	1388	2	5	Genchu.	4	12	19	III	Aizu.
1036	1389	10	3	"	6	9	6	II	Kyoto.
1037	1391	11	20	"	8	10	16	II	"
1038	1395	1	3	O-yei.	1	12	4	I	"
1039	"	3	24	"	2	2	25	II	"
1040	1398	10	27	"	5	9	9	I	"
1041	"	"	29	"	"	"	11	I	"
1042	1400	9	14	"	7	8	17	I	"
1043	"	11	19	"	"	10	24	III	Ise; slightly felt in Kyoto.
1044	1401	12	11	"	8	"	27	I	Kyoto.
1045	1402	3	12	"	9	1	29	II	"
1046	1403	"	17	"	10	2	15	I	Kyoto and Aizu.
1047	"	12	12	"	"	10*	19	I	Kyoto.
1048	"	"	25	"	"	11	3	I	"
1049	1405	8	17	"	12	7	14	II	"
1050	"	10	"	"	"	9	15	I	"
1051	"	12	20	"	13	11	1	II	"
1052	1407	2	21	"	14	1	5	III	Kyoto and Aizu.

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1053	1408	1	21	O-yei.	14	12	14	III	Settsu, accompanied by sea-waves; slightly felt in Kyoto.
1054	"	3	5	"	15	1	28	I	Kyoto.
1055	"	11	13	"	"	10	16	I	Kyoto, two shocks.
1056	"	"	26	"	"	"	29	III	Kyoto.
1057	1409	1	8	"	"	12	13	I	"
1058	"	8	16	"	16	6	26	I	"
1059	1410	3	11	"	17	1	27	II	"
1060	"	5	12	"	"	3	29	I	"
1061	1411	6	6	"	18	5	6	II	"
1062	"	8	22	"	"	7	24	I	"
1063	"	11	4	"	"	10	9	I	"
1064	"	12	24	"	"	11	1	II	"
1065	1412	3	5	"	19	1	13	I	Kyoto, two shocks.
1066	"	"	7	"	"	"	15	I	Kyoto.
1067	"	4	19	"	"	2	29	II	"
1068	"	6	1	"	"	4	13	I	"
1069	"	7	14	"	"	5	26	I	"
1070	1413	12	17	"	20	11	15	II	"
1071	1419	6	11	"	26	5	9	I	"
1072	"	9	22	"	"	8	24	I	"
1073	"			"	"	10		II	Kanto.
1074	1420	8	15	"	27	6	27	II	Kyoto.
1075	"	9	26	"	"	8	10	III	Kamakura.
1076	1421	11	16	"	28	10	13	I	Kyoto.
1077	1422	1	5	"	"	12	3	I	"
1078	"	10	25	"	29	10	1	I	"
1079	1423	3		"	30	3		I	"
1080	"	12		"	"	12		I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1081	1424	6	1	O-yei.	31	4	25	I	Kyoto.
1082	"	10	26	"	"	9	"	I	"
1083	"	"	27	"	"	"	26	I	"
1084	"	"	28	"	"	"	27	I	"
1085	1425	1	3	"	"	12	5	II	"
1086	"	8	10	"	32	6*	17	II	"
1087	"	"	23	"	"	7	1	I	"
1088	"	"	24	"	"	"	2	II	"
1089	"	9	"	"	"	8	4	I	"
1090	"	"	27	"	"	"	7	I	"
1091	"	"		"	"	9		I	"
1092	"	12	13	"	"	10	24	I	"
1093	"	"	23	"	"	11	5	III	"
1094	"	"	28	"	"	"	10	II	"
1095	"	"	30	"	"	"	12	I	"
1096	"	"	31	"	"	"	13	I	"
1097	1426	1	3	"	"	"	16	I	"
1098	"	"	9	"	"	"	22	I	"
1099	"	"	28	"	"	12	11	I	"
1100	"	"	29	"	"	"	12	I	"
1101	"	"	30	"	"	"	13	I	"
1102	"	2	2	"	"	"	16	I	"
1103	"	4	19	"	33	2	22	I	"
1104	"	6	18	"	"	5	4	I	"
1105	"	"	27	"	"	"	13	I	"
1106	"	7	31	"	"	6	18	I	"
1107	"	10	18	"	"	9	9	I	Kyoto, two shocks.
1108	"	"	31	"	"	"	22	II	Kyoto.
1109	"	11	27	"	"	10	19	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1110	1426	12	18	O-yei.	33	11	11	I	Kyoto.
1111	"	"	31	"	"	"	24	I	"
1112	1427	1	3	"	"	"	27	I	"
1113	"	"	26	"	"	12	20	I	"
1114	"	"	29	"	"	"	23	I	"
1115	"	2	1	"	"	"	26	I	"
1116	1428	11	4	Shocho.	1	9	18	II	"
1117	1429	4	17	Yeikyo.	"	3	5	I	"
1118	1431	3	11	"	3	1	18	I	"
1119	"	12	10	"	"	10	27	I	"
1120	"	"	25	"	"	11	12	I	"
1121	1432	4	21	"	4	3	"	II	Kamakura.
1122	1433	2	23	"	5	1	24	III	Ise and Oni ; strongly felt in Kyoto.
1123	"	4	16	"	"	3	17	II	Kyoto; shocks again on the 20th, 25th, 26th and 27th of the same month.
1124	"	5	21	"	"	4	23	I	Kyoto.
1125	"	6	17	"	"	5	21	II	Kamakura.
1126	"	"	18	"	"	"	22	I	Kyoto.
1127	"	11	6	"	"	9	15	I	"
1128	"	"	7	"	"	"	16	III	Shimosa, Aizu, Sagami and Kai ; strongly felt in Kyoto.
1129	"	"	10	"	"	"	19	I	Kyoto.
1130	"	12	17	"	"	10	27	II	"
1131	1134	3	6	"	6	1	16	II	Kamakura.
1132	"	"	12	"	"	"	22	I	Kyoto.
1133	"	"	25	"	"	2	6	I	"
1134	"	4	25	"	"	3	7	I	"
1135	"	7	14	"	"	5	29	II	"
1136	"	11	9	"	"	9	29	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1137	1434	12	5	Yeikyo.	6	10	26	I	Kyoto.
1138	1435	1	9	"	"	12	1	I	"
1139	"	"	21	"	"	"	13	I	"
1140	"	"	22	"	"	"	14	I	"
1141	"	3	6	"	7	1	27	I	"
1142	"	7	17	"	"	6	13	I	"
1143	"	8	9	"	"	7	6	I	"
1144	"	"	16	"	"	"	13	II	"
1145	1436	8	2	"	8	6	11	I	"
1146	"	"	30	"	"	7	9	III	Aizu.
1147	1437	2	3	"	"	12	19	I	Kyoto.
1148	"	5	4	"	9	3	20	I	"
1149	1438	3	13	"	10	2	9	I	"
1150	"	4	18	"	"	3	15	I	"
1151	"	7	6	"	"	6	5	I	"
1152	1439	1	12	"	"	12	18	I	"
1153	"	"	22	"	"	"	28	II	"
1154	1440	10	22	"	12	9	18	III	Aizu ; strongly felt in Kyoto.
1155	1442	3	12	Kakitsu.	2	1	21	II	Kyoto.
1156	"	4	4	"	"	2	14	I	"
1157	"	12	1	"	"	10	20	III	Kotsuke.
1158	1443	2	19	"	3	1	11	I	Kyoto.
1159	"	4	30	"	"	3	21	I	"
1160	"	7	26	"	"	6	20	II	"
1161	"	11	1	"	"	10	1	I	"
1162	"	12	8	"	"	11	8	I	"
1163	1444	5	23	Bun-an.	1	4	27	II	"
1164	1445	1	9	"	"	11	22	III	Kyoto ; after-shocks continued for one month.

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1165	1446	4	4	Bunan.	3	2	29	I	Kyoto.
1166	1447	8	14	"	4	6	24	II	"
1167	1448			"	5			III	Several provinces.
1168	1449	5	13	"	1	4	12	III	Yamashiro and Yama- to ; after shocks con- tinued for 1 month.
1169	"	9	8	"	"	8	12	I	Kyoto.
1170	"	"	15	"	"	"	19	I	"
1171	"	10	6	"	"	9	11	I	"
1172	"	"	13	"	"	"	18	I	"
1173	"	12	27	"	"	11	5	I	"
1174	1450	8	20	Hotoku.	2	7	5	I	"
1175	"	9	11	"	"	"	27	I	"
1176	"	"	12	"	"	"	28	I	"
1177	1451	8	8	"	3	7	3	I	"
1178	"	10	6	"	"	9	3	I	"
1179	"	12	20	"	"	11	18	I	"
1180	1452	1	10	"	"	12	10	II	Kamakura.
1181	"	9	5	Kyotoku.	1	8	13	II	Kyoto.
1182	1454	12	21	"	3	11	23	III	Kotsuke.
1183	1455	1	7	"	"	12	10	II	Kamakura.
1184	1456	2	14	Kosei.	1	"	29	II	Kyoto.
1185	1457	1	1	"	2	11	26	I	"
1186	1458	2	25	Choroku.	2	1*	3	II	"
1187	"	4	7	"	"	2	15	II	"
1188	"	9	10	"	"	7	24	I	"
1189	1459	2	25	"	3	1	13	I	"
1190	1460	3	12	Kansei.	1	2	9	II	Kyoto ; slightly felt at Nara.
1191	"	"	13	"	"	"	10	I	Nara.
1192	"	"	22	"	"	"	19	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1193	1460	3	24	Kansei.	1	2	21	I	Nara.
1194	"	6	23	"	"	5	25	II	Kyoto.
1195	"	8	13	"	"	7	18	I	"
1196	"	9	1	"	"	8	7	I	"
1197	"	"	9	"	"	"	15	I	"
1298	"	"	28	"	"	9	5	I	"
1299	"	10	17	"	"	"	24	I	"
1200	"	"	19	"	"	"	26	I	"
1201	"	11	15	"	"	9*	23	I	"
1202	"	"	16	"	"	"	24	I	"
1203	"	"	18	"	"	"	26	I	"
1204	"	11	27	"	"	10	6	II	"
1205	1462	1	9	"	2	11	30	II	"
1206	1464	5	22	"	5	4	7	II	"
1207	1465	7	4	"	6	6	2	I	Nara.
1208	"	11	5	"	"	10	8	I	Kyoto.
1209	1466	4	6	Bunsei.	1	2*	12	I	"
1210	"	5	29	"	"	4	6	III	Yamashiro and Yama- to.
1211	"	6	17	"	"	"	25	I	Kyoto.
1212	"	"	18	"	"	"	26	I	"
1213	"	11	9	"	"	9	22	I	"
1214	1467	2	12	"	"	12	29	II	"
1215	"	"	13	"	"	"	30	I	"
1216	"	2	14	O-nin.	1	1	1	I	Nara.
1217	"	4	10	"	"	2	27	II	Kyoto; slightly felt at Nara.
1218	"	7	11	"	"	6	2	I	Kyoto.
1219	"	10	27	"	"	9	20	I	"
1220	"	"	29	"	"	"	22	I	"
1221	"	12	13	"	"	11	8	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1222	1468	1	30	O-nin.	1	12	26	I	Kyoto.
1223	"	2	22	"	2	1	20	I	"
1224	"	3	9	"	"	2	6	II	"
1225	"	6	4	"	"	5	5	I	"
1226	"	7	19	"	"	6	21	I	"
1227	"	11	11	"	"	10	18	I	"
1228	1470	5	27	Bunmei.	2	4	18	I	Nara.
1229	1471	2	5	"	3	1	7	II	Nara ; slightly felt in Kyoto.
1230	"	"	6	"	"	"	8	I	Nara.
1231	"	3	30	"	"	2	30	I	"
1232	"	4	4	"	"	3	5	I	"
1233	"	6	11	"	"	5	14	II	Kyoto.
1234	"	"	14	"	"	"	17	I	"
1235	1474	Winter.		"	6	Winter.		III	(District obscure).
1236	1475	2	16	"	7	1	2	I	Kyoto.
1237	"	3	24	"	"	2	8	II	"
1238	"	5	29	"	"	4	16	III	Aizu.
1239	"	11	13	"	"	10	6	I	"
1240	1476	5	19	"	8	4	17	I	Nara.
1241	"	7	16	"	"	6	16	I	Kyoto, three shocks.
1242	1477	1	27	"	9	1	4	I	"
1243	"	11	6	"	"	9	22	I	Nara.
1244	"	12	20	"	"	11	6	II	Kyoto.
1245	"	"	23	"	"	"	9	I	"
1246	1479	5	3	"	11	4	3	I	"
1247	"	9	27	"	"	9	3	III	Aizu.
1248	1481	3	12	"	13	2	3	I	Kyoto.
1249	"	4	26	"	"	3	19	II	Nara, two shocks.
1250	"	8	21	"	"	7	17	I	Nara and Kyoto.

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1251	1482	6	2	Bunmei.	14	5	7	I	Nara and Kyoto.
1252	"	9	8	"	"	7 [*]	16	I	"
1253	"	12	18	"	"	10	29	I	Nara.
1254	1483	2	16	"	"	12	30	II	"
1255	1484	4	5	"	16	3	1	I	"
1256	"	9	18	"	"	8	20	I	"
1257	1486	1	26	"	17	12	12	I	"
1258	"	"	27	"	"	"	13	I	"
1259	"	6	6	"	18	4	25	II	Nara ; slightly in Kyoto.
1260	"	10	17	"	"	9	11	I	Kyoto.
1261	"	"	27	"	"	"	21	I	Nara.
1262	1487	9	2	Chokyo.	1	8	6	I	Kyoto.
1263	1489	2	19	Yentoku.	"	1	10	I	"
1264	"	3	4	"	"	"	23	I	"
1265	"	"	5	"	"	"	24	I	"
1266	"	5	29	"	"	4	20	III	Aizu.
1267	"	8	27	"	"	7	22	II	Kyoto.
1268	"	"	30	"	"	"	25	II	"
1269	"	9	10	"	"	8	6	I	Nara.
1270	"	"	11	"	"	"	7	II	Kyoto.
1271	1491	3	21	"	3	2	2	I	Kyoto and Nara.
1272	"	9	25	"	"	8	13	I	Kyoto.
1273	1492	6	29	Mei-o.	1	5	26	II	"
1274	"	7	19	"	"	6	16	III	Aizu.
1275	1493	4	4	"	2	3	9	I	Kyoto.
1276	"	8	17	"	"	6	26	II	Aizu.
1277	"	12	10	"	"	10	23	I	Nara.
1278	"	"	17	"	"	"	30	II	Kyoto and Nara.
1279	"	"	19	"	"	11	2	I	Kyoto.

No	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1280	1493	12	20	Mei-o.	2	11	3	II	Nara; slightly felt in Kyoto.
1281	"	"	31	"	"	"	14	I	Nara.
1282	1494	1	1	"	"	"	15	I	Kyoto.
1283	"	"	20	"	"	12	4	I	"
1284	"	2	9	"	"	"	24	I	Nara.
1285	"	"	21	"	3	1	7	III	Aizu.
1286	"	6	19	"	"	5	7	III	Kyoto and Nara; after-shocks continued for 8 months.
1287	1495	2	11	"	4	1	7	I	Nara.
1288	"	"	17	"	"	"	13	II	Nara; slightly felt in Kyoto.
1289	"	6	30	"	"	5	29	I	Kyoto.
1290	"	9	12	"	"	8	15	I	"
1291	1496	4	2	"	5	2 nd	10	I	"
1292	1497	7	22	"	6	5	13	I	Settsu.
1293	"	11	21	"	"	10	18	II	Kyoto.
1294	1498	2	1	"	7	1	1	I	Nara.
1295	"	"	5	"	"	"	5	I	"
1296	"	"	8	"	"	"	8	I	"
1297	"	3	26	"	"	2	25	I	Kyoto.
1298	"	7	9	"	"	6	11	III	Kyoto and several provinces; after-shocks continued for several days.
1299	"	9	20	"	"	8	25	III	Kyoto, Yamato, Ise, Mikawa, Totomi, Suruga, Izu, Sagami, Kai, Kii and Aizu; with sea-waves along the coasts of Kii, Ise, Mikawa, Totomi, Suruga, Izu and Sagami.
1300	"	12	9	"	"	10 th	17	II	Nara and Kyoto.
1301	"	"	25	"	"	11	4	I	Kyoto.
1302	"	"	28	"	"	"	7	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1303	1499	1	19	Mei-o.	7	11	29	I	Kyoto.
1304	"	2	22	"	8	1	4	I	Kyoto and Nara.
1305	"	4	15	"	"	2	26	I	Kyoto.
1306	"	4	17	"	8	2	28	II	Nara; slightly felt in Kyoto.
1307	"	5	26	"	"	4	8	I	Kyoto, three shocks.
1308	"	6	2	"	"	"	15	I	Kyoto.
1309	"	7	21	"	"	6	4	I	Nara.
1310	"	8	25	"	"	7	10	II	Kyoto and Nara.
1311	"	"	31	"	"	"	16	I	Kyoto and Yamato.
1312	"	9	20	"	"	8	6	I	Kyoto.
1313	"	11	4	"	"	9	22	I	"
1314	1500	1	11	"	"	12	2	II	Kyoto; slightly felt at Nara.
1315	"	"	15	"	"	"	5	I	Kyoto.
1316	"	2	20	"	9	1	12	I	"
1317	"	4	3	"	"	2	26	II	Kyoto; slightly felt at Nara.
1318	"	5	29	"	"	4	23	I	Kyoto.
1319	"	7	10	"	"	6	4	III	Kai, followed by several minor shocks.
1320	"	"	31	"	"	"	25	I	Kyoto.
1321	"	10	4	"	"	9	1	I	"
1322	1501	12	26	Bunki.	1	11	6	I	"
1323	1502	1	28	"	"	12	10	III	Echigo.
1324	1503	5	15	"	3	4	10	I	Kyoto.
1325	"	9	27	"	"	8	27	I	"
1326	1504	"	23	Yeisho.	1	8	6	II	"
1327	1505	10	2	"	2	8	25	I	"
1328	1506	11	12	"	3	10	17	I	"
1329	"	12	15	"	"	11	21	II	"
1330	"	"	17	"	"	"	23	I	"
1331	1507	1	22	"	"	11*	29	II	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1332	1507	3	31	Yeisho.	4	2	8	III	IIgo, shakings continued for 32 days; strongly felt in Kyoto.
1333	"	5	28	"	"	4	7	I	Kyoto.
1334	1508	9	12	"	5	8	7	I	"
1335	1509	4	6	"	6	3	"	I	"
1336	"	5	7	"	"	4	9	I	"
1337	1510	9	21	"	7	8	8	III	Kyoto, Settsu and Kawachi; with sea-waves along the coast of Settsu.
1338	"	"	22	"	"	"	9	I	Kyoto.
1339	"	10	7	"	"	"	24	I	"
1340	"	"	10	"	"	"	27	III	Totomi, with sea-waves.
1341	1511	2	8	"	"	12	30	I	Kyoto.
1342	"	3	30	"	8	2	21	I	"
1343	"	5	24	"	"	4	17	I	"
1344	"	8	7	"	"	7	4	I	"
1345	"	9	9	"	"	8	7	III	Hitachi.
1346	"	12	2	"	"	11	2	I	Kyoto.
1347	1512	3	6	"	9	2	8	II	"
1348	"	7	31	"	"	6	9	III	Yamashiro.
1349	"	8	1	"	"	"	10	I	Kyoto.
1350	"	"	4	"	"	"	13	I	"
1351	"	"	20	"	"	"	29	I	"
1352	1514	1	13	"	10	12	8	II	"
1353	"	5	28	"	11	4	24	II	"
1354	"	9	23	"	"	8	25	I	"
1355	1516	4	13	"	13	3	2	II	"
1356	"	8	20	"	"	7	12	III	Kai, 9 shocks during two days.
1357	1517	6	18	"	14	5	19	II	Kyoto.
1358	"	7	18	"	"	6	20	III	Aizu.

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1359	1517	10	4	Yeisho.	14	9	9	II	Kyoto.
1360	1519	4	27	„	16	3	18	II	„
1361	1520	„	4	„	17	„	7	I	„
1362	„	12	1	„	„	10	11	II	„
1363	1521	10	21	Taiyui.	1	9	11	II	Nara.
1364	„	11	28	„	„	10	19	II	Kyoto and Nara.
1365	1524	„	2	„	4	9	26	I	Kyoto.
1366	1525	6	2	„	5	5	2	I	„
1367	„	9	20	„	„	8	23	III	Kamakura, Aizu.
1368	1526	11	26	„	6	10	12	I	Kyoto.
1369	„	„	28	„	„	„	14	I	„
1370	1527	3	25	„	7	2	13	II	„
1371	1529	12	18	Kyoroku.	2	11	8	I	Settsu.
1372	1531	7	19	„	4	5*	25	I	Kyoto.
1373	1532	3	6	Tenmon.	1	1	20	III	Sanuki ; after-shocks continued for one week.
1374	1533	2	19	„	2	1	16	I	Kyoto.
1375	„	3	27	„	„	2	22	I	„
1376	„	10	25	„	„	9	27	I	„
1377	1536	2		„	5	1		I	Kai.
1378	1538	1	16	„	6	12	6	I	Mikawa.
1379	1542	3	24	„	11	2	28	I	Kyoto, Omi.
1380	1544	5	23	„	13	4	22	III	Satsuma.
1381	1545			„	14	3		III	„
1382	1549	3	9	„	18	1	30	II	Kyoto.
1383	„	5	21	„	„	4	14	III	Kai ; after-shocks continued for 30 days.
1384	1550	8	14	„	19	6	22	I	Kyoto.
1385	1553	10	11	„	22	8	24	III	Kamakura.
1386	1554	12	11	„	23	11	7	I	Kyoto.

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1387	1555	9	14	Ko-ji.	1	8	19	III	Aizu.
1388	1556	4	3	"	2	2	13	II	Kyoto.
1389	1557	7	26	"	3	6	20	II	"
1390	1558	6	25	"	1	5	29	I	"
1391	1562	4	22	Yeiroku.	5	3	9	I	Kyoto.
1392	1563	2	28	"	6	1	26	III	Hitachi, Aizu.
1393	"	9	22	"	"	8	25	I	Kyoto.
1394	"	12	27	"	"	12	2	III	Musashi, Hitachi, and Aizu.
1395	1564	4	27	"	7	3	7	II	Kyoto.
1396	"	5	23	"	"	4	3	I	"
1397	1565	8	24	"	8	7	19	I	"
1398	1566	2	23	"	9	1	23	I	"
1399	1567	12	19	"	10	11	9	I	"
1400	1568	6	13	"	11	5	8	I	"
1401	"	"	30	"	"	"	25	I	"
1402	"	10	7	"	"	9	7	I	"
1403	"	11	14	"	"	10	15	I	"
1404	"	"	27	"	"	"	28	I	"
1405	1569	11	11	"	12	9	23	I	"
1406	1570	3	27	Genki.	1	2	11	I	Kyoto, Omi.
1407	"	"	28	"	"	"	12	I	Omi.
1408	"	4	23	"	"	3	8	I	Kyoto.
1409	"	6	22	"	"	5	9	I	"
1410	1572	3	14	"	3	1*	20	II	Nara.
1411	"	"	22	"	"	"	28	I	Kyoto.
1412	"	7	3	"	"	5	13	I	"
1413	"	"	20	"	"	6	1	II	Kyoto and Nara.
1414	1573	1	1	"	"	11	18	I	Kyoto.
1415	1575	7	22	Tensho.	3	6	5	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1416	1576	12	8	Tensho.	6	10	29	III	Mikawa.
1417	1579	"	19	"	7	11	21	II	Nara.
1418	1582	9	16	"	10	8	20	II	"
1419	"	"	19	"	"	"	23	I	Kyoto.
1420	1583	2	10	"	11	1	18	II	Nara.
1421	"	4	24	"	"	3	3	I	Mikawa.
1422	"	"	25	"	"	"	4	I	"
1423	"	8	13	"	"	6	23	I	"
1424	1585	7	31	"	13	7	5	III	Mikawa ; strongly felt in Yamato.
1425	1586	1	18	"	"	11	29	III	Yamashiro, Yamato, Kawachi, Izumi, Settsu, Mikawa, Ise, Owari, Mino, Hida, Omi, Sanuki and Hokuroko-do ; after-shocks continued in Kyoto for 4 $\frac{1}{2}$ months, at Nara for 5 months, and in Mikawa for 2 $\frac{1}{2}$ months.
1426	1587	8	9	"	15	7	2	I	Mikawa.
1427	"	"	26	"	"	"	19	I	"
1428	1588	10	29	"	16	9	10	I	Kyoto.
1429	1589	3	21	"	17	2	5	III	Suruga and Totomi.
1430	"	4	17	"	"	3	3	I	Nara.
1431	1590	10	30	"	18	10	2	I	Yedo.
1432	"	11	13	"	"	"	16	I	"
1433	"	12	18	"	"	11	22	I	"
1434	1592	10	8	Bunroku.	1	9	3	II	"
1435	1593	5	14	"	2	4	14	I	Kyoto.
1436	"	10	19	"	"	9	25	I	"
1437	1595	2	12	"	4	1	4	II	"
1438	1596	9	1	Keicho.	1	7*	9	III	Satsuma ; slightly felt in Kyoto.
1439	"	"	4	"	"	"	12	III	Kyoto, Kinai provinces, Kii and Chikuzen ; after-shocks continued for 6 months.

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1440	1598	2	11	Keicho.	3	1	6	I	Kyoto.
1441	"	"	16	"	"	"	11	I	"
1442	"	"	19	"	"	"	14	I	"
1443	"	3	5	"	"	"	28	I	"
1444	"	"	10	"	"	2	3	I	"
1445	1599	11	20	"	"	10	3	I	"
1446	"	"	21	"	"	"	4	I	"
1447	"	"	22	"	"	"	5	I	"
1448	"	12	22	"	"	11	5	I	"
1449	1600	7	23	"	5	6	13	III	Tsugarn, the Iwaki-sun erupted.
1450	1601	3	11	"	6	2	7	I	Kyoto.
1451	"	5	16	"	"	4	14	I	"
1452	1602	4	16	"	7	2	24	I	"
1453	"	5	6	"	"	3	15	I	"
1454	"	"	10	"	"	"	19	I	"
1455	"	"	17	"	"	"	26	I	"
1456	"	6	21	"	"	5	2	I	"
1457	"	"	22	"	"	"	3	I	"
1458	"	7	7	"	"	"	18	I	"
1459	"	"	30	"	"	6	12	I	"
1460	1603	4	26	"	8	3	15	I	"
1461	"	6	7	"	"	4	28	II	Yedo.
1462	"	7	7	"	"	5	28	I	Kyoto.
1463	"	12	29	"	"	11	27	I	"
1464	1604	1	22	"	"	12	21	II	"
1465	"	"	23	"	"	"	22	II	"
1466	"	"	24	"	"	"	23	I	"
1467	"	3	12	"	9	2	12	I	"
1468	"	6	3	"	"	5	6	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1469	1604	7	9	Keicho.	9	6	13	I	Kyoto.
1470	"	"	21	"	"	"	25	I	"
1471	"	"	22	"	"	"	26	I	"
1472	"	8	12	"	"	7	17	II	"
1473	"	"	17	"	"	"	22	I	"
1474	"	"	20	"	"	"	25	I	"
1475	"	"	28	"	"	8	4	I	"
1476	"	12	31	"	"	11	11	I	"
1477	1605	1	29	"	"	12	14	I	"
1478	"	"	31	"	"	"	16	III	Kanto, Hachijo-shima, Ise, Shikoku and Kiushu, with seawaves along the coasts of Satsuma, Tosa, Ise, Totomi, Izu, Awa, Kazusa, Shimosa and Hachijo-shima.
1479	"	3	29	"	10	2	10	I	Suruga.
1480	"	8	26	"	"	7	12	I	Kyoto.
1481	1606	1	5	"	"	11	27	I	"
1482	"	7	5	"	11	6	1	I	Yedo.
1483	"	"	7	"	"	"	3	I	"
1484	1607	2	2	"	12	1	6	II	"
1485	"	"	16	"	"	"	20	II	"
1486	"	3	3	"	"	2	6	I	"
1487	"	5	23	"	"	4	28	I	Kyoto.
1488	"	8	5	"	"	6	13	I	Sampr.
1489	1609	2	20	"	14	1	16	I	Tsugaru.
1490	"	6	9	"	"	5	8	I	Kyoto.
1491	"	10	16	"	"	9	19	I	"
1492	"	12	17	"	"	11	21	I	"
1493	1610	2	11	"	15	1	18	I	Tsugaru.

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1494	1610	3	2	Keicho.	15	2	7	I	Kyoto.
1495	"	12	27	"	"	11	13	I	"
1496	1611	2	23	"	16	1	11	I	"
1497	"	4	5	"	16	2	22	I	Sumpu.
1498	"	9	27	"	"	8	21	III	Aizu.
1499	"	11	7	"	"	10	3	I	Sumpu.
1500	"	12	2	"	"	10	28	III	Sendai and the eastern coast of Ezo, accompanied by sea-waves.
1501	1612	3	22	"	17	2	20	I	Sumpu.
1502	1613	1	3	"	"	11	13	I	Yedo.
1503	"	11	13	"	18	10	1	I	Kyoto.
1504	1614	2	1	"	"	12	23	I	"
1505	"	5	23	"	19	4	15	I	"
1506	"	"	30	"	"	"	22	I	"
1507	"	8	28	"	"	7	23	I	"
1508	"	9	28	"	"	8	25	I	Sumpu.
1509	"	10	9	"	"	9	6	I	"
1510	"	11	26	"	"	10	25	III	Kyoto, Odawara and Takata, with sea-waves along the coast of Echigo.
1511	1615	2	27	Genwa.	1	1	30	I	Kyoto.
1512	"	6	26	"	"	6	1	III	Yedo.
1513	"	9	6	"	"	7	14	I	Kyoto.
1514	1616	3	5	"	2	1	18	I	"
1515	"	9	9	"	"	7	28	III	Sendai.
1516	"	10	26	"	"	9	16	I	Kyoto.
1517	"	11	18	"	"	10	10	I	"
1518	1617	3	7	"	3	1	30	I	"
1519	"	12	27	"	"	11	30	I	Shimotsuke.
1520	1618	6	19	"	4	4	27	I	Kyoto.

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1521	1618	9	30	Genwa.	4	8	12	I	Kyoto.
1522	1620	2	6	"	6	1	3	I	"
1523	"	5	7	"	"	4	5	I	"
1524	"	8	12	"	"	7	14	I	"
1525	"	10	16	"	"	9	21	I	"
1526	1622	11	18	"	8	10	16	II	Kyoto.
1527	"	12	20	"	"	11	18	I	"
1528	1624	6	19	Kan-yei.	1	5	4	III	Shinotsuke.
1529	"	11	9	"	"	9	29	II	Kyoto.
1530	1625	8	7	"	2	7	5	I	"
1531	"	10	3	"	"	9	2	I	"
1532	"	"	4	"	"	"	3	I	"
1533	1627	3	8	"	4	1	21	II	Yedo.
1534	"	4	9	"	"	2	23	I	Yamashiro.
1535	"	7	13	"	"	6	1	I	Kyoto.
1536	1628	2	21	"	5	1	17	I	"
1537	"	6	2	"	"	5	1	I	"
1538	"	"	17	"	"	"	16	I	Yedo.
1539	"	"	19	"	"	"	18	II	"
1540	"	8	10	"	"	7	11	III	"
1541	1629	4	8	"	6	2 nd	15	I	Kyoto.
1542	"	"	9	"	"	"	16	I	"
1543	"	8	16	"	"	6	27	I	"
1544	"	12	6	"	"	10	22	I	"
1545	1630	8	1	"	7	6	23	III	Yedo.
1546	1631	1	15	"	"	12	13	I	"
1547	"	"	27	"	"	"	25	II	"
1548	1632	2	21	"	9	1	2	I	"
1549	"	3	3	"	"	"	13	I	Kyoto.

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1550	1632	3	27	Kan-yei.	9	2	7	I	Kyoto.
1551	"	8	2	"	"	6	17	I	Yedo.
1552	"	10	12	"	"	8	29	I	"
1553	"	"	15	"	"	9	2	I	"
1554	"	11	13	"	"	10	2	I	"
1555	"	12	8	"	"	10	27	I	"
1556	1633	2	8	"	"	12	30	I	"
1557	"	"	16	"	10	1	8	I	"
1558	"	3	1	"	"	"	21	III	Odawara and Kanto, with sea-waves at Atami; strongly felt in Yedo. After- shocks continued for about one month.
1559	"	5	17	"	"	4	10	I	Yedo.
1560	"	11	16	"	"	10	15	I	"
1561	1634	5	6	"	11	4	9	I	Kyoto.
1562	1635	3	12	"	12	1	23	III	Yedo.
1563	"	7	31	"	"	6	18	I	"
1564	"	10	6	"	"	8	25	I	"
1565	"	11	9	"	"	9	30	I	"
1566	1636	1	5	"	"	11	27	I	Kyoto.
1567	"	2	21	"	13	1	15	I	Yedo.
1568	"	"	22	"	"	1	16	I	"
1569	"	"	23	"	"	1	17	I	"
1570	"	9	4	"	"	8	5	I	"
1571	"	10	28	"	"	9	31	I	"
1572	"	"	29	"	"	10	1	I	"
1573	"	"	31	"	"	"	3	I	"
1574	"	11	14	"	"	"	17	I	"
1575	1637	8	29	"	14	7	10	I	"
1576	"	9	21	"	"	8	3	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1577	1637	9	28	Kan-yei.	14	8	10	I	Yedo.
1578	"	"	29	"	"	"	11	I	"
1579	"	10	17	"	"	"	29	I	"
1580	1639			"	16	11		III	Echizen.
1581	1643	6	15	"	20	4	29	I	Yedo.
1582	1643	12	6	"	20	10	26	I	"
1583	1644	2	13	Shoho.	1	1	6	I	Kyoto.
1584	"	"	26	"	1	"	19	I	"
1585	"	4	12	"	"	3	6	I	"
1586	"			"	"			III	Nikko.
1587	"	8	5	"	"	7	3	I	Kyoto.
1588	"	10	18	"	"	9	18	III	Honjo (in Ugo).
1589	1645	2	15	"	2	1	19	II	Yedo.
1590	1646	6	9	"	3	4	26	III	Sendai, Mutsu and Dewa; on the same day, two small shocks felt in Yedo.
1591	"	12	21	"	"	11	15	II	Kyoto.
1592	1647	6	16	"	4	5	14	III	Yedo and Sagami.
1593	"	9	3	"	"	8	5	I	Yedo.
1594	"	"	25	"	"	"	27	I	"
1595	1648	6	12	Keian.	1	4	22	III	Sagami; felt strongly in Yedo, and slightly in Kyoto.
1596	1649	3	14	"	2	2	2	I	Kyoto.
1597	"	"	16	"	"	"	4	I	Yedo.
1598	"	"	17	"	"	"	5	III	Aki and Iyo.
1599	"	5	11	"	"	3	30	I	Yedo.
1600	"	6	30	"	"	5	21	I	"
1601	"	7	30	"	"	6	21	III	Yedo and Nikko.
1602	"	9	1	"	"	7	25	III	Yedo.
1603	"	"	3	"	"	"	27	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1604	1649	9	10	Keian.	2	8	4	I	Yedo.
1605	"	"	11	"	"	"	5	I	"
1606	"	"	26	"	"	"	20	I	"
1607	1650	4	24	"	3	3	24	I	"
1608	1652	12	1	Sho-o.	1	11	1	I	"
1609	1659	4	21	Manji.	2	2	30	III	Mutsu and Shimotsuke; strongly felt in Yedo.
1610	1661	8	4	Kanbun.	1	7	10	III	Higo.
1611	"	12	10	"	"	10	19	III	Tosa.
1612	1662	2	5	"	2	1	18	I	Kyoto.
1613	"	5	12	"	"	3	24	III	Kyoto, Yamashiro, Kawachi and Settsu; strongly felt in Yedo.
1614	"	6	16	"	"	5	1	III	Kyoto, Yamashiro, Yamato, Izumi, Settsu, Iga, Ise, Shinano, Omi, Mino, Tamba, Tango, Wakasa and Hizen; after-shocks continued for more than 6 months.
1615	"	10	30	"	"	9	19	III	Hiuga and Osumi, accompanied by sea-waves.
1616	1663	8	17	"	3	7	15	III	Oshima and Iburi, the Utsu-san erupted.
1617	"	12	6	"	"	11	7	I	Yedo.
1618	"	"	27	"	"	"	23	I	Hizen, the Unsendake erupted.
1619	1664	1	4	"	"	12	6	III	Kyoto and Yamashiro.
1620	"	5	20	"	4	4	25	I	Yedo.
1621	"	8	3	"	"	6	12	III	Kii; slightly felt in Kyoto.
1622	1665	2	16	"	5	1	2	I	Kyoto.
1623	"	4	16	"	"	3	1	I	"
1624	"	5	24	"	"	4	10	I	Higo.
1625	"	6	12	"	"	"	29	II	Yedo.

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1626	1665	6	19	Kanbun.	5	5	6	I	Kyoto.
1627	"	"	25	"	"	"	12	III	"
1628	"	9	14	"	"	8	6	I	"
1629	"	10	11	"	"	9	3	I	Yedo.
1630	1666	2	1	"	"	12	27	III	Takata (Echigo).
1631	"	5	31	"	6	4	28	I	Yedo.
1632	"	8	30	"	"	8	1	I	Tajima.
1633	1668	2	24	"	8	1	13	I	Yedo.
1634	"	3	5	"	"	"	23	I	"
1635	"	8	28	"	"	7	21	III	Sendai.
1636	1669	9	6	"	9	8	11	II	Yedo.
1637	1670	6	22	"	10	5	5	I	Sado.
1638	"	7	21	"	"	6	5	III	Osumi-gun (Sagami).
1639	"	12	20	"	"	11	8	I	Yedo.
1640	1671	1	11	"	11	12	12	I	Yedo ; ashes fell.
1641	1672	1	11	"	12	1	13	I	Yedo.
1642	"	"	20	"	"	"	22	I	"
1643	"	2	29	"	"	2	1	I	"
1644	1673	7	28	Yenpo.	1	6	15	I	Kyoto.
1645	1674	8	9	"	2	7	8	I	Yedo.
1646	1676	1	16	"	3	12	2	I	Sado.
1647	"	7	12	"	4	6	2	III	Tsuwano (Iwami.)
1648	1677	4	13	"	5	3	12	III	Tsugaru and Nanbu, accompanied by sea-waves.
1649	1768	10	2	"	6	8	17	II	Yedo.
1650	1681	9	13	Tenwa.	1	8	2	I	"
1651	1682	2	9	"	2	1	2	I	Kyoto.
1652	"	11	9	"	"	10	10	I	"
1653	1683	5	1	"	3	4	5	I	Nikko.

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1654	1683	6	11	Tenwa.	3	5	17	II	Nikko.
1655	"	"	18	"	"	"	24	III	Nikko; strongly felt in Yedo.
1656	"	10	20	"	"	9	1	III	Nikko.
1657	"	3	31	Teikyo.	1	2	16	I	O-shima erupted (Izu).
1658	"	4	8	"	"	"	24	I	Kyoto.
1659	"	6	29	"	"	5	17	I	"
1660	1684	8	12	"	1	7	2	I	Kyoto.
1661	"	9	27	"	"	8	18	I	"
1662	"	11	21	"	"	10	15	I	"
1663	1685	10	8	"	2	9	11	III	Suwo and Nagato; slightly felt in Kyoto.
1664	"	11	22	"	"	10	26	I	Yedo.
1665	1686	1	15	"	"	12	21	I	"
1666	"	7	14	"	3	5	24	I	"
1667	"	10	3	"	"	8	16	III	Totomi and Mikawa; slightly felt in Kyoto.
1668	"	"	21	"	"	9	5	I	Kyoto.
1669	"	11	7	"	"	"	22	I	"
1670	1687	10	30	"	4	9	25	I	Yedo.
1671	1688	3	21	Genroku.	1	2	20	I	Kyoto.
1672	"	6	24	"	"	5	27	I	"
1673	"	11	24	"	"	11	2	I	"
1674	"	"	29	"	"	"	7	I	"
1675	"	12	5	"	"	"	13	I	"
1676	1689	5	17	"	2	3	28	I	"
1677	"	7	26	"	"	6	10	I	"
1678	1690	2	15	"	3	1	7	I	"
1679	1691	5		"	4	5		I	Higo, the Aso-san erupted.
1680	1692	5	1	"	5	4	16	I	Kyoto.

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1681	1693	2	25	Gen-roku.	6	1	21	I	Kyoto.
1682	1694	6	19	"	7	5	27	III	Akita (in Ugo) and Shonai and Noshiro (in Uzen).
1683	1696	5			8	4		III	Higo.
1684	1696	7	17		9	6	19	I	Yedo.
1685	"	"	19	"	"	"	21	I	"
1686	1697	11	23	"	10	10	7	I	Yedo.
1687	"	"	25	"	"	"	12	III	Kanakura; strongly felt in Yedo.
1688	1698	2	14	"	11	1	4	I	Kyoto.
1689	1699	9	23	"	12	9	1	III	Kii.
1690	1703	12	31	"	16	11	23	III	Musashi, Sagami, Kai, Suruga, Izu, Awa, Kazusa, Shimosa and Mutsu, & with sea-waves along the coasts of Awa, Sagami and Izu; after-shocks conti- nued for about 6 months.
1691	1706	10	21	Ho-yei.	3	9	15	II	Yedo.
1692	"	12	9	"	"	11	5	I	Sado.
1693	1707	10	28	"	4	10	4	III	Bungo, Iyo, Tosa, Awa, (in Shikoku), Sanuki, Yamashiro, Yamato, Kawachi, Settsu, Omi Ise, Owari, Mikawa, Totomi, Suruga, & Kai, Izu, and other provinces in the Sanindo, Sanyodo and Saikaido accom- panied by sea-waves along the coasts of Hiuga, Bungo, Nagato, Iyo, Tosa, Awa, (in Shikoku), Settsu, To- tomi, Ise and Izu.
1694	"	12	16	"	"	11	23	III	Suruga, Kai and Sagami (the Fuji- san erupted); the shock felt slightly in Yedo.
1695	1708	2	15	"	5	1	24	I	Yedo.
1696	"	"	16	"	"	"	25	I	"
1697	"	"	17	"	"	"	26	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1698	1708	2	18	Ho-yei.	5	1	27	I	Yedo.
1699	"	5	21	"	"	4	2	I	Kyoto.
1700	1709	3	19	"	8	2	1	III	Minasaka, Inaba and Hoki; slightly felt in Kyoto.
1701	1714	4	28	Shotoku.	4	3	15	III	Shinano.
1702	1717	2	13	Kyoho.	2	1	3	III	Hinga, the Kirishimasan erupted.
1703	1717	2	18	"	2	1	8	I	Yedo.
1704	"	6	6	"	"	4	27	I	Kyoto.
1705	"	7	9	"	"	6	1	I	"
1706	"	9	20	"	"	8	16	I	"
1707	1718	1	12	"	"	12	11	I	Yedo.
1708	"	3	11	"	3	2	10	I	"
1709	"	6	28	"	"	6	1	I	Kyoto.
1710	"	8	22	"	"	7	26	III	Yamashiro, Shinano, Totomi and Mikawa; strongly felt in Kyoto.
1711	"	12	13	"	"	10*	22	I	Kyoto.
1712	1719	5	7	"	4	3	18	I	Echigo.
1713	1720	2	15	"	5	1	8	I	Kyoto.
1714	"	4	3	"	"	2	26	I	"
1715	"	7	9	"	"	6	4	I	"
1716	1722	4	2	"	7	2	17	I	"
1717	"			"	"	12		I	Shinano, the Asamasan erupted.
1718	1723	3	9	"	8	2	3	I	Kyoto.
1719	"	12	17	"	"	11	20	III	Saikaido; after-shocks continued till the next month.
1720	1724	1	5	"	"	12	10	I	Kyoto.
1721	"	6	21	"	9	5	1	I	"
1722	"	7	13	"	"	"	23	I	"
1723	"	8	8	"	"	6	20	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1724	1725	4	18	Kyoho.	10	3	6	I	Kyoto.
1725	"	10	30	"	"	9	25	III	"
1726	1726	4	20	"	11	3	19	I	Nagasaki.
1727	"	9	11	"	"	8	16	I	Echizen.
1728	1727	1	24	"	12	1	3	I	Kyoto.
1729	"	2	13	"	"	"	23	I	"
1730	1727	10	27	"	12	9	13	I	"
1731	1728	11	8	"	13	10	7	I	"
1732	1729	8	1	"	14	7	7	III	Noto and Sado.
1733	1731	9	20	"	16	8	20	I	Kyoto.
1734	"	10	7	"	"	9	7	III	Kori (in Mutsu).
1735	"	11	13	"	"	10	14	I	Kyoto.
1736	"	12	19	"	"	11	21	I	"
1737	"	"	30	"	"	12	2	I	"
1738	1732	1	29	"	17	1	3	II	Yedo.
1739	1733	5	27	"	18	4	16	I	Kyoto.
1740	1734	11	20	"	19	10	27	I	Yedo.
1741	"	12	1	"	"	11	7	I	Kyoto.
1742	1735	5	6	"	20	3*	14	I	Yedo.
1743	1737	4	30	Genbun.	2	4	1	I	"
1744	"	7	28	"	"	7	1	I	"
1745	"	10	26	"	"	10	3	I	Kyoto.
1746	"	11	29	"	"	11	8	I	Yedo.
1747	1740	2	27	"	5	2	1	I	"
1748	"	5	20	"	"	4	25	I	Kyoto.
1749	"	7	20	"	"	6	27	I	"
1750	"	10	21	"	"	9	1	I	Yedo.
1751	1741	10	12	Kampo.	1	9	3	I	"
1752	1743	7	1	"	3	5	10	I	Kyoto.

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1753	1744	1	8	Kampo.	3	11	24	I	Kyoto.
1754	"	"	9	"	"	"	25	I	"
1755	1745	3	2	"	2	1	30	I	"
1756	"	6	21	Yenkyo.	2	5	22	I	"
1757	1746	3	30	"	3	2	9	I	"
1758	"	4	7	"	"	"	17	I	"
1759	1746	5	14	"	3	3	24	II	Yedo.
1760	"	12	11	"	"	10	29	I	Kyoto.
1761	1747	3	13	"	4	2	3	I	"
1762	"	6	1	"	"	4	24	I	"
1763	1748	1	27	"	"	12	27	I	"
1764	1749	11	26	Kan-yen.	2	10	17	I	"
1765	"			"	"	Winter.		I	Osaka, several shocks.
1766	1750	2	27	"	3	1	21	I	Kyoto.
1767	"	8	31	"	"	7	30	I	"
1768	"	9	1	"	"	8	1	I	"
1769	"	11	28	"	"	10	30	I	"
1770	"	12	8	"	"	11	10	I	"
1771	1751	3	26	Horeki.	1	2	29	II	"
1772	"	"	27	"	"	3	1	I	"
1773	"	"	28	"	"	"	2	I	"
1774	"	"	29	"	"	"	3	I	"
1775	"	"	30	"	"	"	4	I	"
1776	"	4	11	"	"	"	16	I	"
1777	"	"	14	"	"	"	19	I	"
1778	"	5	20	"	"	4	25	III	Takata (in Echigo); after-shocks continued for several months.
1779	"	7	17	"	"	6	25	I	Kyoto.
1780	1753	2	11	"	3	1	9	II	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1781	1753	3	20	Horeki.	3	2	16	I	Yedo.
1782	1755	4	21	"	5	3	10	II	Nikko (in Shimo-tsuke).
1783	1758	3	28	"	8	2	19	I	Kyoto.
1784	"	"	29	"	"	"	20	I	"
1785	1760	5	14	"	10	3	29	I	"
1786	"	"	19	"	"	4	5	I	"
1787	1762	5	11	"	12	4	18	I	"
1788	"	10	31	"	"	9	15	III	Sado.
1789	1763	3	16	"	13	2	2	I	Kyoto.
1790	"	4	5	"	"	"	22	I	"
1791	1765	9	22	Meiwa.	2	8	8	I	Sado.
1792	1766	3	8	"	3	1	28	III	Tsugaru and Aomori.
1793	1768	10	15	"	5	9	5	I	Sado.
1794	1769	8	29	"	6	7	28	III	Sadowara (in Hiuga).
1795	1770	9	19	"	7	8	1	I	Sado.
1796	1771	6	14	"	8	5	2	I	Yedo.
1797	"	7	13	"	"	6	2	I	"
1798	"	11	24	"	"	10	18	I	Sado.
1799	1772	6	3	An-yei.	1	5	3	I	Kyoto.
1800	1773	9	26	"	2	8	10	I	Sado.
1801	1774	1	10	"	"	11	28	I	Yedo.
1802	"	"	23	"	"	12	11	I	Kyoto.
1803	"	2	9	"	"	"	28	I	Yedo.
1804	"	"	11	"	"	"	30	I	"
1805	"	3	14	"	3	2	3	I	Kyoto.
1806	"	4	14	"	"	3	4	I	"
1807	"	5	3	"	"	"	23	I	"
1808	"	6	25	"	"	5	17	I	"
1809	1775	2	15	"	4	1	16	I	"

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1810	1776	10	22	An-yei.	5	9	10	I	Kyoto.
1811	"	12	3	"	"	10	23	I	"
1812	1777	3	20	"	6	2	11	I	"
1813	"	"	21	"	"	"	12	I	"
1814	1778	3	3	"	7	2	5	I	Sadowara.
1815	"	"	22	"	"	"	24	I	Kyoto.
1816	"	4	1	"	"	3	4	I	Sado.
1817	"	6	28	"	"	6	4	I	Kyoto.
1818	1779	3	4	"	8	1	17	I	Sado.
1819	"	5	25	"	"	4	10	I	Kyoto.
1820	"	11	8	"	"	10	1	II	Satsuma and Osumi, the Sakura-shima erupted.
1821	"	12	6	"	"	"	29	I	Kyoto.
1822	"	"	17	"	"	11	10	II	Sado.
1823	1780	4	16	"	9	3	12	II	Yedo.
1824	"	8	24	"	"	7	24	I	Sado.
1825	"	10	24	"	"	9	27	I	Kyoto.
1826	1781	3	7	Tenmei.	1	2	13	I	Sado.
1827	1782	8	23	"	2	7	15	III	Yedo and Sagami.
1828	1783	3	4	"	3	2	2	II	Yedo.
1829	"	8	5	"	"	7	8	II	Shinano; the Asama- yama erupted.
1830	1786	3	22	"	6	2	23	I	Sagami.
1831	1789	4	10	Kansei.	1	3	15	I	Sado.
1832	1790	2	25	"	2	1	12	I	Kyoto.
1833	"	3	16	"	"	2	1	I	"
1834	"	"	24	"	"	"	9	I	"
1835	"	11	7	"	"	10	1	I	"
1836	1791	1	1	"	"	11	27	II	Yedo.
1837	"	1		"	"	12		I	Yedo, several shocks.

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1838	1791	9	13	Kansei.	3	8	16	I	Kyoto.
1839	1792	4	21	„	4	3	1	III	Shimabara (in Hizen); the Fuku-san erupted. After- shocks continued for 9 months.
1840	1793	2		„	5	1		I	Kanto Provinces.
1841	„	6	11	„	„	5	3	I	Kyoto.
1842	„	„	13	„	„	„	5	I	„
1843	„	„	14	„	„	„	6	I	„
1844	1794	11	25	„	6	11	3	II	Yedo.
1845	1797	9	2	„	9	7*	12	I	Kyoto.
1846	„	„	12	„	„	„	22	I	„
1847	1799	4	9	„	11	3	5	I	„
1848	1802	11	18	Kyowa.	2	10	23	I	„
1849	„	„	24	„	„	„	29	I	„
1850	„	12	9	„	„	11	15	III	Sado, accompanied by sea-waves; after- shocks continued for 8 months.
1851	1803	4	25	„	3	3	4	II	Yedo.
1852	1804	7	13	Bunka.	1	6	7	III	Shonai (in Dewa).
1853	1806	3	22	„	3	2	3	I	Yedo.
1854	„	4	13	„	„	„	25	I	„
1855	„	6	8	„	„	4	22	I	„
1856	„	8	27	„	„	7	14	I	„
1857	„	12	1	„	3	10	22	I	„
1858	1807	3	29	„	4	2	21	I	„
1859	1810	2	4	„	7	1	1	III	Sado.
1860	1812	3	17	„	9	2	5	I	Kyoto.
1861	„	12	7	„	„	11	4	III	Omi and neighbouring provinces.
1862	1814	3	26	„	11	2	5	I	Kyoto.
1863	1815	3	2	„	12	1	22	III	Kaga.

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1864	1819	8	2	Bunsei.	2	6	12	III	Ise, Mino, Settsu and Yamashiro.
1865	1821	12	13	"	4	11	19	III	Onuma-gun, Aizu (Iwashiro).
1866	1822	3	12	"	5	1 st	19	II	Yezo, the Usu-dake erupted; shaking continued for one month.
1867	1824	2	13	"	7	1	14	I	Kyoto.
1868	1826			"	9	Spring.		I	Yedo, several shocks.
1869	"			"	"	Winter.		I	"
1870	1828	12	18	"	11	11	12	III	Echigo.
1871	1830	8	19	Tempo.	1	7	2	III	Yamashiro, Wakasa, Tanba and Omi; after-shocks continued for 6 months.
1872	1831	11	13	"	2	10	10	III	Hizen.
1873	1833	12	7	"	4	10	26	III	Sado, accompanied by sea-waves.
1874	1834	2	9	"	5	1	1	III	Ishikari.
1875	"	5	16	"	"	4	8	II	Suruga and Kai, the Fuji-san erupted.
1876	1835	7	20	"	6	6	25	I	Yedo.
1877	"	8	19	"	"	7	25	III	Mutsu and Nemuro, accompanied by great sea-waves.
1878	1838	1	4	"	8	12	9	I	Yedo.
1879	1841	5		"	12	4		III	Suruga.
1880	1843	3	9	"	14	2	9	I	Yedo.
1881	"	4	25	"	"	3	26	III	Kushiro, accompanied by sea-waves.
1882	1844	5	8	Koka.	4	3	24	III	Shinano and Echigo.
1883	1853	3	11	Ka-yei.	6	2	2	III	Sagami, Suruga, Izu, Mikawa and Tōtomi.
1884	1854	7	9	Ansei.	1	6	15	III	Yamashiro, Yamato, Kawachi, Izumi, Settsu, Omi, Tanba, Kii, Echizen, Iga and Ise.

No.	EUROPEAN DATE.			JAPANESE DATE.				Intensity.	DISTRICT.
	Year	Month	Day	Period	Year	Month	Day		
1885	1854	12	23	Ansei.	1	11	4	III	Hiuga, Hizen, Higo, Chikuzen, Satsuma, Osumi, Chikugo, Buzen, Bungo, Nagato, Suwo, Aki, Bingo, Bitchu, Bizen, Harima, Iyo, Tosa, Awa (in Shikoku), Sanuki, Awaji, Kii, Yamashiro, Yamato, Kawachi, Settsu, Tango, Iwami, Izumo, Wakasa, Echizen, Totomi, Suruga, Kai, Izu, Sagami, Musashi, Omi, Mino, Shinano, and Shimotsuke; accompanied by sea-waves along the coasts of Bungo, Tosa, Awa (in Shikoku), Settsu, Ise, Shima, Totomi and Izu. After shocks continued for several years.
1886	1855	11	11	"	2	10	2	III	Yedo.
1887	1856	8	23	"	3	7	23	III	Iburi and Oshima; accompanied by sea-waves.
1888	"	11	4	"	"	10	7	II	Yedo.
1889	1857	7	14	"	4	5*	23	III	Suruga; strongly felt in Yedo.
1890	"	10	15	"	"	8	28	III	Iyo.
1891	1858	4	8	"	5	2	25	I	Kyoto.
1892	"	"	9	"	"	"	26	III	Yechizen and Etchu; weakly felt in Kyoto.
1893	"	"	23	"	"	3	10	III	Shinano.
1894	1858	12	23	"	"	11	19	I	Kyoto.
1895	1859	5	28	"	6	4	26	I	"
1896	1861	2	26	Bunkyo.	1	2	16	I	Yedo.
1897	"	9	29	"	"	8	25	I	"
1898	1864	6	6	Ganji.	1	5	3	I	"

Notes on the Earthquake Investigation Committee Catalogue of Japanese Earthquakes.

By

F. Omori, D.Sc.

I. INTRODUCTION.

1. The *Earthquake Investigation Committee Catalogue of Japanese Earthquakes*¹ includes the records of 1898 earthquakes, which took place in Japan² during the 1451 years between the 5th year of Inkio Tenno (416 A.D.) and the 3rd year of Kei-o (1867 A. D.), each great earthquake and its after-shocks being counted in it as one. As the development of seismic literature depends much on the state of civilization of the times, the majority of old earthquake records relate naturally to Kyoto, which was the capital between 797 and 1867, A.D. Many earthquakes were also recorded in Kamakura and then in Yedo (Tokyo), when these places were the seat of the *Shogunate*, or military regency.

2. The number of earthquakes described in original histories and manuscripts as *great earthquakes* or *great shakings of the ground* amounts to 449. All of these earthquakes, however, were not destructive, some being nothing more than shocks, in which

1) Compiled under the superintendence of the late Prof. Sekiya. This volume, pp. 315-388.

2) Liu-kiu Islands and Formosa excluded.

the ground moved more or less sharply without producing any damage. For the sake of making the Catalogue more definite I have classified the earthquakes contained in it into the following three kinds, according to the intensity of their motion :

Great or destructive earthquakes, in which the ground was cracked, buildings greatly damaged, lives lost, etc.;

Strong earthquakes, in which the motion was sufficiently sharp to cause people to run out of doors and to produce slight damage, such as the overthrowing of furnitures, small cracks in walls and *ishigaki* (masonry walls), embankments, etc.;

Small or slight earthquakes, in which the motion was weak and which caused neither alarm nor damage.

It may here be remarked that the relation between the absolute intensity of the earthquake motion and the amount of damage produced would not necessarily be the same in different countries. Thus, the houses in Japan are mostly constructed of wood and resist earthquake shocks much better than buildings in European cities which are often high and constructed of stone or brick, generally without any precautions being taken against earthquakes. An earthquake classed as *strong* in the Catalogue, might therefore have produced considerable damage, had it affected an European city.

II. Number of Destructive Earthquakes in Japan.

3. It is no easy matter to classify earthquakes accurately according to the scale in § 2, since some of the old earthquake records are too simple and make no reference to the intensity of motion or to the area of disturbance. In recognising which

were destructive among the earthquakes in Japan recorded in the original histories and journals, I have been guided by the following considerations :

- (a) A shock whose destructive characters are clearly described, may be considered as a *destructive earthquake* ;
- (b) A shock in Kyoto, Kamakura or Yedo (Tokyo), which is recorded simply as a *great earthquake*, but whose destructive effects are not specially mentioned, was presumably a *strong earthquake* ;
- (c) A shock recorded, as a *great earthquake*, whose area of disturbance was very extensive or whose after-shocks were numerous, may be presumed as a *destructive earthquake* even when there exists no special description of the destructive effects ;
- (d) A shock in a remote province, which is recorded as a *great earthquake*, may generally have been a *destructive earthquake*, even when there exists no special description of the destructive effects.

4. The total number of destructive earthquakes in Japan estimated on these principles and counting to the end of the year 1898, is two hundred and twenty-two, whose dates and districts are given in Table I. I will note here that the date of destructive shocks in Liu-kiu Islands and the provinces of Tsushima and Kaga, whose original records are not yet in the hands of the Earthquake Investigation Committee, have provisionally been taken from the late Mr. H. Okajima's "Nippon Saiishi" or *A History of Unusual Events in Japan*. Again a few records relating to Hokkaido have been taken from "Hokkaido-shi" or *History and Geography of Hokkaido*.

1) Formosa excepted.

TABLE I.
DESTRUCTIVE EARTHQUAKES IN JAPAN.¹

No.	EUROPEAN DATE.			JAPANESE DATE.				DISTRICT.
	Year	Month	Day	Period	Year	Month	Day	
1	416	8	23	Inkio-Tenno.	5	7	14	Kawachi.
2	599	5	28	Suiko-Tenno.	7	4	27	Yamato.
3	678	1		Tennu-Tenno.	6	12		Chikushi.
4	684	11	29	"	12	10	14	Iyo, Tosa, Awa (in Shikoku), Kii, Yamato, Ise, Shima, Mikawa, Totomi, Suruga and Izu.
5	701	5	12	Taiho.	1	3	26	Tanba.
6	715	7	4	Reiki.	1	5	25	Totomi.
7	"	"	5	"	"	5	26	Mikawa.
8	734	5	18	Tenpei.	6	4	7	Nara (in Yamato) and several provinces.
9	737	11	28	"	9	10	23	Osumi.
10	744	6	30	"	16	5	12	Higo.
11	745	6	5	"	17	4	27	Mino.
12	"	"	9	"	17	5	1	Settsu.
13	762	6	9	Tenpei-hoji.	6	5	9	Mino, Iida and Shinano.
14	766	7	20	Tenpei-shingo.	2	6	5	Osumi.
15	818			Konin.	9	7		Sagami, Musashi, Shimosa, Hitachi, Kotsuke and Shimotsuke.
16	827	8	11	Tencho.	4	7	12	Kyoto.
17	830	2	3	"	7	1	3	Akita (in Ugo).
18	841	3	13	Showa.	8	2	13	Shinano.
19	"	7	30	"	"	7	5	Izu.
20	850	11	27	Kasho.	3	10	16	Dewa.
21	856	4		Saiko.	3	3		Kyoto.

¹) A month in old Japanese calendar marked with an asterisk (*) is the extra or intercalary month of the same name.

No.	EUROPEAN DATE.			JAPANESE DATE.				DISTRICT.
	Year	Month	Day	Period	Year	Month	Day	
22	863	7	10	Jokan.	5	6	17	Echu and Echigo.
23	864	8	26	„	6	7	17	Fuji-san erupted and its vicinity shaken.
24	867	6	21	„	9	5	12	Aso-san erupted and its vicinity shaken.
25	868	8	3	„	10	7	8	Kyoto, Harima, Tanba and Settsu.
26	869	7	13	„	11	5	26	Mutsu.
27	878	11	1	Genkei.	2	9	29	Kanto provinces, especially Musashi and Sagami.
28	880	11	23	„	4	10	14	Izumo; strongly felt in Kyoto.
29	881	1	13	„	4	12	6	Kyoto.
30	887	8	26	Ninwa.	3	7	30	Kyoto and several provinces, especially Settsu and Shinano.
31	934	7	16	Shohei.	4	5	27	Kyoto.
32	938	5	22	Tengyo.	1	4	15	Kyoto, Yamashiro and Yamato.
33	976	7	22	Teigen.	1	6	18	Kyoto.
34	1041	8	25	Chokiu.	2	7	20	„
35	1070	12	1	Yenkiu.	2	10	20	Kyoto, Nara, and several provinces.
36	1091	9	28	Kanji.	5	8	7	Kyoto.
37	1096	12	17	Yeicho.	1	11	24	„
38	1137	8	10	Hoyen.	3	7	15	„
39	1177	11	26	Jisho.	1	10	27	Nara; strongly felt in Kyoto.
40	1180	12	21	„	4	11	26	Kii.
41	1185	8	13	Bunji.	1	7	9	Kyoto.
42	1186	10	3	„	2	8	12	„
43	1213	6	18	Kenpo.	1	5	21	Kamakura.
44	1215	10	7	„	3	9	6	„
45	1227	4	1	Antei.	1	3	7	„
46	„	12	22	„	„	11	6	„
47	1235	4	5	Katei.	1	3	9	„
48	1241	3	27	Ninji.	2	2	7	„

No.	EUROPEAN DATE.			JAPANESE DATE.				DISTRICT.
	Year	Month	Day	Period	Year	Month	Day	
49	1241	5	22	Ninji.	2	4	3	Kamakura.
50	1245	8	26	Kangen.	3	7	26	Kyoto.
51	1250	8	24	Kencho.	2	7	18	Kamakura.
52	1257			Shoka.	1	Spring.		Tsushima.
53	"	10	9	"	"	8	23	Kamakura.
54	1273	4	5	Bunyei.	10	3	9	Aizu (in Iwashiro).
55	1293	5	27	Yeinin.	1	4	13	Kamakura and Kanto provinces.
56	1325	12	5	Seichu.	2	10	21	Kinai provinces; strongly felt in Kyoto.
57	1331	8	15	Genko.	1	7	3	Kii and several other provinces.
58	"	"	19	"	"	7	7	Suruga.
59	1350	7	6	Shohei.	5	5	23	Kyoto.
60	1361	8	1	"	16	6	22	Kii, Yamato, Kawachi, Izumi and Settsu; strongly felt in Kyoto.
61	"	"	3	"	"	"	24	Yamato, Kawachi, Settsu, Izumi, Awaji, Kii and Awa (in Shikoku).
62	1375	5	23	Tenju.	1	4	14	Aizu (in Iwashiro).
63	1388	2	5	Genchu.	4	12	19	"
64	1400	11	19	O-yei.	7	10	24	Kyoto, Ise and Iga.
65	1407	2	21	"	14	1	5	Aizu (in Iwashiro) and several provinces; strongly felt in Kyoto.
66	1408	1	27	"	"	12	14	Settsu; slightly felt in Kyoto.
67	"	11	26	"	15	10	29	Kyoto.
68	1420	9	26	"	27	8	10	Kamakura (in Sagami).
69	1425	11	23	"	32	11	5	Kyoto.
70	1433	2	23	Yeikyo.	5	1	24	Ise and Omi; strongly felt in Kyoto.
71	"	11	7	"	"	9	16	Shimosa, Sagami, Kai and Aizu (in Iwashiro); strongly felt in Kyoto.
72	1436	8	30	"	8	7	9	Aizu (in Iwashiro).
73	1440	10	22	"	12	9	18	Aizu; strongly felt in Kyoto.

No.	EUROPEAN DATE.			JAPANESE DATE.				DISTRICT.
	Year	Month	Day	Period	Year	Month	Day	
74	1442	12	1	Kakitsu.	2	10	20	Kozuke.
75	1445	1	9	Bun-an.	1	11	22	Kyoto.
76	1448			"	5			Several provinces.
77	1449	5	13	Hotoku.	1	4	12	Kyoto, Yamashiro and Yamato.
78	1454	12	21	Kyotoku.	3	11	23	Kozuke.
79	1466	5	29	Bunsho.	1	4	6	Yamashiro and Yamato.
80	1474			Bunmei.	6	Winter.		(District not known).
81	1475	5	29	"	7	4	16	Aizu (in Iwashiro).
82	1479	9	27	"	11	9	3	"
83	1489	5	29	Yentoku.	1	4	20	"
84	1492	7	19	Mei-o.	1	6	16	"
85	1494	2	21	"	3	1	7	"
86	"	6	19	"	"	5	7	Nara; strongly felt in Kyoto.
87	1498	7	9	"	7	6	11	Several provinces; strongly felt in Kyoto.
88	"	9	20		7	8	25	Kii, Yamato, Iga, Ise, Owari, Mikawa, Totomi, Suruga, Kai, Izu, Sagami, Musashi, Awa, Kazusa, Shimosa, Shimotsuke, Hitachi and Iwashiro; strongly felt in Kyoto.
89	1500	7	10	"	9	6	4	Kai.
90	1502	1	28	Bunki.	1	12	10	Echigo.
91	1507	3	31	Yeisho.	4	2	8	Ihigo; strongly felt in Kyoto.
92	1510	9	21	"	7	8	8	Settsu and Kawachi; strongly felt in Kyoto.
93	"	10	10	"	"	8	27	Totomi.
94	1511	9	9	"	8	8	7	Hitachi.
95	1512	3	6	"	9	2	8	Strongly felt in Kyoto, probably a great earthquake in the vicinity.
96	"	7	31	"	"	6	9	Yamashiro and probably also other provinces.
97	1516	8	20	"	13	7	12	Kai.

No.	EUROPEAN DATE.			JAPANESE DATE.				DISTRICT.
	Year	Month	Day	Period	Year	Month	Day	
98	1517	7	18	Yeisho.	14	6	20	Aizu (in Iwashiro).
99	1525	9	20	Taiyei.	5	8	23	Kamakura and Aizu (in Iwashiro).
100	1532	3	6	Tenmon.	1	1	20	Sanuki.
101	1544	5	23	„	13	4	22	Satsuma.
102	1545			„	14	3		„
103	1549	5	21	„	18	4	14	Kai.
104	1553	10	11	„	22	8	24	Kamakura.
105	1555	9	14	Koji.	1	8	19	Aizu (in Iwashiro).
106	1563	2	28	Yeiroku.	6	1	26	Hitachi, Iwaki, Shimotsuke and Aizu (in Iwashiro).
107	„	12	27	„	„	12	2	Musashi, Shimotsuke, Hitachi, Iwaki and Aizu (in Iwashiro).
108	1578	12	8	Tensho.	6	10	29	Mikawa.
109	1585	7	31	„	13	7	5	„
110	1586	1	15	„	„	11	26	Kaga.
111	„	„	18	„	„	„	29	Sanuki, Awaji, Wakasa, Echizen, Kaga, Hida, Yamashiro, Yamato, Kawachi, Izumi, Settsu, Omi, Mino, Iga, Ise, Mikawa and Omari.
112	1589	3	21	„	17	2	5	Suruga and Totomi.
113	1596	9	1	Keicho.	1	7*	9	Kyoto and Satsuma.
114	„	„	4	„	„	„	12	Kyoto and Kinai provinces, Kii, Chikuzen, and several other provinces.
115	1600	7	23	„	5	6	13	Tsugaru (in Mutsu), the Iwakisan erupted.
116	1605	1	31	„	9	12	16	Kii, Ise, Shima, Owari, Mikawa, Totomi, Suruga, Izu, Awa, Kazusa, Shimosa, Hachijo-shima, and provinces in Kiushiu and Shikoku.
117	1611	9	27	„	16	8	21	Aizu (in Iwashiro).
118	„	12	2	„	„	10	28	Sendai (in Rikuzen) and Yezo.

No.	EUROPEAN DATE.			JAPANESE DATE.				DISTRICT.
	Year	Month	Day	Period	Year	Month	Day	
119	1614	11	26	Keicho.	19	10	25	Takata (in Echigo); strongly felt in Kyoto and at Odawara (in Sagami).
120	1615	6	26	Genwa.	1	6	1	Yedo.
121	1616	9	9	"	2	7	28	Sendai (in Rikuzen).
122	1624	6	19	Kan-yei.	1	5	4	Shimotsuke.
123	1628	8	10	"	5	7	11	Yedo.
124	1630	8	1	"	7	6	23	"
125	1633	3	1	"	10	1	21	Odawara (in Sagami) and Kanto.
126	1635	3	10	"	12	1	21	Mutsumaye (in Oshima).
127	"	"	12	"	"	"	23	Yedo.
128	1639	11		"	16	11		Echizen.
129	1644	3		Shoho.	1	3		Nikko (in Shimotsuke).
130	"	10	18	"	"	9	18	Honjo (in Ugo).
131	1646	6	9	"	3	4	26	Sendai, Mutsu and Dewa.
132	1647	6	16	"	4	5	14	Yedo and Sagami.
133	1648	6	12	Kei-an.	1	4	22	Sagami; strongly felt in Yedo.
134	1649	3	17	"	2	2	5	Aki and Iyo (slightly felt in Kyoto).
135	"	7	30	"	"	6	21	Yedo and Nikko (in Shimotsuke).
136	"	9	1	"	"	7	25	Yedo.
137	1659	4	21	Manji.	2	2	30	Shimotsuke, Iwaki and Iwashi- shiro; strongly felt in Yedo.
138	1661	12	10	Kanbun.	1	10	19	Tosa.
139	1662	5	12	"	2	3	24	Kyoto, Yamashiro, Kawachi and Settsu; strongly felt in Yedo.
140	"	6	16	"	2	5	1	Kyoto, Yamashiro, Yamato, Kawachi, Izumi, Settsu, Wakasa, Tanba, Iga, Ise, Owari, Mikawa, Omi, Mino, Shinano and Hizen.

No.	EUROPEAN DATE.			JAPANESE DATE.				DISTRICT.
	Year	Month	Day	Period	Year	Month	Day	
141	1662	10	30	Kanban.	2	9	19	Hiuga and Osumi.
142	1663	8	17	"	3	7	15	Oshima and Iburi, the Usudake erupted.
143	1664	1	4	"	"	12	6	Kyoto and Yamashiro.
144	"	8	3	"	4	6	12	Kii.
145	"			"	"			Liu-kiu.
146	1665	6	25	"	5	5	12	Kyoto.
147	1666	2	1	"	"	12	27	Takata (in Echigo).
148	1668	8	28	"	8	7	21	Sendai (in Rikuzen).
149	1670	7	21	"	10	6	5	Osumi (in Sagami).
150	"	9	28	"	"	8	15	Tsushima.
151	1676	7	12	Yenpo.	4	6	2	Tsuwano (in Iwami).
152	1677	4	13	"	5	3	12	Tsugaru (in Rikuoku).
153	1683	6	18	Tenwa.	3	5	24	Nikko (in Shimotsuke); strongly felt in Yedo.
154	"	10	20	"	"	9	1	Nikko.
155	1685	10	8	Teikyo.	2	9	11	Suwo and Nagato; strongly felt in Kyoto.
156	1686	10	3	"	3	8	16	Totomi and Mikawa; slightly felt in Kyoto.
157	1694	6	19	Genroku.	7	5	27	Shonai (in Uzen), and Akita and Noshiro (in Ugo).
158	1697	11	25	"	10	10	12	Sagami, especially Kamakura; strongly felt in Yedo.
159	1699	9	23	"	12	9	1	Kii.
160	1700	4	16	"	13	2	27	Tsushima.
161	1703	12	31	"	16	11	23	Yedo, Musashi, Sagami, Kai, Awa, Kazusa, Shimosa, Suruga, Izu, Hitachi and Iwaki.
162	1706			Hoyei.	3			Miyako-shima (Liu-kiu).
163	1707	10	28	"	4	10	4	Hiuga, Bungo, Sanuki, Iyo, Tosa, Awa (in Shikoku), Awaji, Harima, Kii, Yamashiro, Yamato, Kawachi, Settsu, Izumi, Omi, Mino, Shinano, Ise, Shima, Owari, Mikawa, Totomi, Suruga, Izu, Sagami, Kai, and other provinces in Kiushiu and Sanyodo; strongly felt in Yedo.

No.	EUROPEAN DATE.			JAPANESE DATE.				DISTRICT.
	Year	Month	Day	Period	Year	Month	Day	
164	1707	12	16	Hoyei.	4	11	23	Suruga and Totomi, the Fujisan erupted.
165	1709	3	11	"	8	2	1	Mimasaka, Inaba and Iloki; slightly felt in Kyoto.
166	1714	4	28	Shotoku.	4	3	15	Shinano.
167	1718	8	22	Kyoho.	3	7	26	Yamashiro, Shinano, Totomi and Mikawa; strongly felt in Kyoto.
168	1723	12	17	"	8	11	20	Saikaido provinces.
169	1725	10	30	"	10	9	25	Nagasaki.
170	1729	8	1	"	14	7	7	Noto and Sado.
171	1730	3	12	"	15	1	24	Tsushima.
172	1731	10	7	"	16	9	7	Ko-ori (in Iwashiro).
173	1751	5	20	Horeki.	1	4	25	Takata (in Echigo).
174	1762	10	31	"	12	9	15	Sado.
175	1766	3	8	Meiwa.	3	1	28	Mutsu and Oshima.
176	1769	8	29	"	6	7	28	Sadowara (in Hiuga).
177	1778	2	14	Anyei.	7	1	18	Aki, Bizen, Eitchu and Bingo.
178	1780	5		"	9	4		Urup Island (Chishima).
179	1782	8	23	Tenmei.	2	7	15	Yedo and Sagami.
180	1792	4	21	Kansei.	4	3	1	Hizen, the Unsen-dake erupted.
181	1798	7	8	"	10	5	25	Kaga.
182	1802	12	9	Kyowa.	2	11	15	Sado.
183	1804	7	13	Bunka.	1	6	7	Shonai (in Uzen).
184	1810	2	4	"	7	1	1	Sado.
185	1812	12	7	"	9	11	4	Yedo and neighbouring provinces.
186	1815	3	2	"	12	1	22	Kaga.
187	1819	8	2	Bunsei.	2	6	12	Yamashiro, Yamato, Kawa- chi, Settsu, Omi, Mino, Iga and Ise.
188	1821	12	13	"	4	11	19	Onuma-gun (in Iwashiro).
189	1822	3	12	"	5	1 st	19	Yezo; the Usu-dake erupted.

No.	EUROPEAN DATE.			JAPANESE DATE.				DISTRICT.
	Year	Month	Day	Period	Year	Month	Day	
190	1828	12	18	Bunsei.	11	11	12	Sanjo, Mitsuke, Nagaoka, Yoita and Wakino (all in Echigo).
191	1830	8	19	Tenpo.	1	7	2	Kyoto, Yamashiro, Wakasa, Tanba and Omi.
192	1831	11	13	"	2	10	10	Hiizen.
193	1833	12	7	"	4	10	26	Sado.
194	1834	2	9	"	5	1	1	Ishikari.
195	1835	8	19	"	6	7	25	Rikuzen, Rikuchiu, Mutsu and Nemuro.
196	1841	5		"	12	4		Suruga.
197	1843	4	25	"	14	3	26	Kushiro and Nemuro.
198	1844	5	11	Koka.	4	3	24	Shinano and Echigo.
199	1853	3	11	Ka-yei.	6	2	2	Odawara, Sagami, Suruga, Izu, Totomi and Mikawa.
200	1854	7	9	Ansei.	1	6	15	Echigo, Tanba, Harima, Yamashiro, Yamato, Kawachi, Izumi, Settsu, Echizen, Omi, Mino, Iga, Ise, Owari, Mikawa and Kii.
201	"	12	23	"	1	11	4	Buzen, Bungo, Hiizen, Hiigo, Chikuzen, Chikugo, Hiinga, Osumi, Satsuma, Harima, Bizen, Bitchiu, Bingo, Aki, Suwo, Nagato, Echigo, Izumo, Iwami, Wakasa, Echizen, Kii, Awaji, Awa (in Shikoku), Samuki, Iyo, Tosa, Yamashiro, Yamato, Kawachi, Izumi, Settsu, Omi, Shinano, Mino, Iga, Ise, Shima, Owari, Mikawa, Totomi, Suruga, Kai, Izu, Sagami, Musashi and Shimotsuke.
202	1855	11	11	"	2	10	2	Yedo, Musashi, Sagami and Shimosa.
203	1856	8	23	"	3	7	23	Hakodate (in Oshima) and Yufutsu (in Iburi).
204	1857	6	14	"	4	5*	23	Suruga.
205	"	10	15	"	4	8	28	Iyo.
206	1858	4	9	"	5	2	26	Echizen and Etchuu.

No.	EUROPEAN DATE.			JAPANESE DATE.				DISTRICT.
	Year	Month	Day	Period	Year	Month	Day	
207	1858	4	23	Ansei.	5	3	10	Shinano.
208	1872	3	14	Meiji.	5	2	6	Iwami.
209	1874	2	28	„	7	2	28	Teshiwo.
210	1881	10		„	14	10		Kumashiri Island (Chishima).
211	1889	7	28	„	22	7	28	Kumamoto.
212	1891	10	28	„	24	10	28	Mino, Owari, Echizen, Mikawa, Settsu, Yamashiro, Yamato, Kawauchi, Ise, Omi, Shinano and Totomi.
213	1892	12	9	„	25	12	9	Noto.
214	1893	9	7	„	26	9	7	Kagoshima (in Satsuma).
215	1894	3	22	„	27	3	22	Nemuro, Kushiro and Kumashiri Island.
216	„	6	20	„	27	6	20	Tokyo and vicinity.
217	„	10	22	„	27	10	22	Shonai (in Uzen).
218	1896	6	15	„	29	6	15	Great sea-waves along the eastern coast of the north Japan.
219	„	8	31	„	„	8	31	Ugo and Rikuchiu.
220	1897	1	17	„	30	1	17	Nagano (in Shinano).
221	„	2	20	„	„	2	20	Sendai and eastern part of Rikuzen.
222	1898	8	10	„	31	8	10	Chikuzen.

TABLE II.

Number of Destructive Earthquakes in Japan.

Century.	Number of destructive earthquakes.	Century.	Number of destructive earthquakes.
V	1	XIII	13
VI	1	XIV	8
VII	2	XV	25
VIII	10	XVI	26
IX	16	XVII	45
X	3	XVIII	22
XI	4	XIX	41
XII	5	Sum	222

5. From Table II it will be seen that the numbers of destructive earthquakes in the 5th, 6th, and 7th centuries are very few. This circumstance may of course be due to the imperfection of historical records in those early times, it being only from the end of the 7th century that the records begin to augment. Taking as starting point December, 678 A.D., when the first of the two destructive earthquakes in the 7th century took place, we have 220 such earthquakes in Japan¹ in the interval of 1220 years down to the end of 1898, there being on the average one destructive earthquake in every 5 years and 7 months. As, however, the earthquake records in old times, which relate to remote provinces, would naturally be imperfect, the above average interval between two successive destructive shocks is without doubt somewhat longer than what was actually the case. On

1) Formosa excepted.

the other hand, in the epoch of the Tokugawa Shogunate which began from the commencement of the 17th century, the records of destructive earthquakes must, except for Hokkaido and Liu-kiu Islands, be very nearly perfect, as it was the rule of the Government to let each feudal chief send in a detailed report of the damage caused in his dominion by an earthquake or other natural events. The earliest recorded earthquake in Hokkaido happened on the 2nd December, 1611, and that in Liu-kiu Islands first in 1664.

In the interval of 299 years from the begining of the 17th century to the end of the year 1898 there were in Japan¹ one hundred and eight destructive earthquakes, of which eleven happened in Hokkaido, and two in Liu-kiu Islands. The mean interval of time between two successive destructive earthquakes in this epoch was, therefore, for the whole of Japan,¹ 2 years and 9 months, or, excluding Hokkaido and Liu-kiu Islands, 3 years and 2 months.

From the above we may conclude that one part or other of Japan¹ is likely to be visited by a destructive earthquake once in nearly every $2\frac{1}{2}$ years on the average.

III. Annual Variation of the Frequency of Destructive Earthquakes.

6. The relation of destructive earthquakes to time may be considered under two heads: their distribution through the year, and their distribution in historic times, of which the former or the annual variation of the frequency of destructive earthquakes in Japan will be taken first.

1) Formosa excepted.

Tables III, IV and V respectively show the monthly, seasonal and half-yearly distribution of all the destructive earthquakes contained in Table I, except six whose exact dates are not recorded.

TABLE III.

Monthly Distribution of 216 Destructive Earthquakes in Japan.

Month.	Number of earthquakes.
I	10
II	13
III	18
IV	12
V	18
VI	19
VII	23
VIII	32
IX	16
X	19
XI	14
XII	22

TABLE IV.

Seasonal Distribution of 216 Destructive Earthquakes in Japan.

Season.	Number of earthquakes.
Spring { March. April. May.	48
Summer { June. July. August.	74
Autumn { September. October. November.	49
Winter { December. January. February.	45

TABLE V.

Semi-annual Distribution of 216 Destructive Earthquakes in Japan.

Division of the year.	Number of earthquakes.
Warmer months { April, May, June, July, August, September.	120
Colder months { October, November, December, January, February, March.	96

According to Table III, the maximum monthly number of 32 occurred in August and the minimum of 10 in January, the ratio of these two numbers being as 3.2:1.

According to Table IV, the maximum seasonal number of 74 occurred in Summer, and the minimum of 45 in Winter, the ratio of these two numbers being as 1.6:1. The numbers for Spring, Autumn and Winter, do not, however, differ much among themselves.

Further, according to Table V, the earthquake number in the warmer months of the year was greater in the ratio of 1.3:1 than that in the colder months.

The results contained in Tables III and IV are illustrated respectively in figs. 1 and 3, the curves being drawn, not always through representation points themselves, but by free-hand through the positions of the arithmetical means of two successive points. The same method of curve-drawing has been employed in all the other similar figures.

7. For the sake of comparing the annual variation of the frequency of destructive earthquakes with that of ordinary small ones, or those which are not the after-shocks of great earthquakes, I give in Table VI the monthly numbers of earthquakes observed in whole of Japan¹ during ten years between 1885 and 1894.

The enormous rise in earthquake numbers after November 1891 is due to the occurrence of the Mino-Owari earthquake on the 28th October, 1891, of the Kagoshima earthquake on the 7th September, 1893, of the Hokkaido earthquake on the 20th March, 1894, and several other strong earthquakes, each of which was followed by a great number of after-shocks. Hence,

1) Formosa and Liu-kiu Islands excepted.

only the earthquake numbers for the months between January, 1885, and October,¹ 1891, have been utilised in deducing the mean monthly earthquake frequencies given at the bottom of the Table, which are intended to represent the approximate state of seismic activity in *ordinary* times, namely, in those years free from destructive earthquakes and their after-shocks, the numbers for the six months, from July to December, 1889, having also been left out of account, in order to exclude the greater portion of the after-shocks of the Kumamoto earthquake of the 28th July, 1889.

In Tables VII and VIII are given respectively the seasonal and the semi-annual distribution of *ordinary* or non-destructive earthquakes deduced from Table VI.

TABLE VI.

Monthly Number of Earthquakes in Japan,² during 10 years, 1885-1894.

Month Year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Sum
1885	32	44	37	37	51	46	32	30	45	41	47	40	482
1886	38	59	49	38	58	30	36	46	41	33	22	42	472
1887	41	58	30	29	60	38	38	35	43	20	35	56	483
1888	53	77	46	42	69	40	40	34	42	47	85	55	630
1889	53	57	63	67	60	39	65	192	79	103	82	70	930
1890	86	65	83	80	93	66	59	55	48	63	98	49	845
1891	34	70	64	83	66	59	57	72	31	98	1412	624	2670
1892	411	263	148	162	137	93	111	116	163	123	119	132	1918
1893	118	90	128	109	115	156	102	77	297	136	102	106	1536
1894	415	182	570	244	144	170	121	250	154	189	150	140	2729
Mean.	48.1	58.6	53.1	53.7	65.3	45.4	43.7	45.3	41.7	50.3	57.4	48.4	

1) The earthquake number for October 1891 does not include the after shocks or the Mino-Owari Earthquake of the 28th of the same month.

2) Formosa and Liu-kiu Islands excepted.

TABLE VII.

Mean Seasonal Distribution of Earthquakes in Japan.¹

Season.	Spring { March. April. May.	Summer { June. July. August.	Autumn { September. October. November.	Winter { December. January. February.
Number of eqkes.	172	134	149	155

TABLE VIII.

Mean Semi-Annual Distribution of Earthquakes in Japan.¹

Division of the year.	Warmer Months. (April, May, June, July, August, September.)	Colder Months. (October, November, December, January, February, March.)
Number of eqkes.	295	316

According to Table VI, the greatest monthly number 65.3 occurred in May, and the smallest numbers, varying between 41.7 and 45.4, in the months of June, July, August and September, the ratio of the maximum to the minimum being as 1.6:1. According to Table VII, the maximum seasonal number

1) Based on the earthquake numbers given in Table VI for the months between January 1885 and October 1891.

of 172 occurred in Spring, and the minimum of 134 in Summer, the ratio of the two numbers being as 1.3:1. Finally, according to Table VIII, the number of earthquakes in the warmer months of the year was greater in the ratio of 1.1:1 than that in the colder months. The results contained in Tables VI and VII are illustrated in figs. 2 and 4.

8. Comparing figs. 1 and 3 with figs. 2 and 4, the annual variation of the frequency of *ordinary* small shocks, whose minimum occurs in the months of June, July, August and September, will be observed to be just the reverse of that of destructive earthquakes, whose maximum occurs in the months of July and August.¹

To explain this fact, we may remark that the geotechnic disturbances, which caused the destructive earthquakes given in Table I, were most probably greater than those of the majority of the ordinary earthquakes included in Table VI. Now, as an earthquake implies the removal of a weak point in the earth's crust, and the consequent settling of the latter to a stable equilibrium, the constant occurrence of small earthquakes is, for unstable countries like Japan, to be regarded as maintaining the region concerned in a normal or safe condition, thereby preventing any abnormal accumulation of stress in the earth's crust. Their non-occurrence, or an unusually low seismic frequency may, on the other hand, cause an accumulation of stress in the earth's crust, thereby facilitating the occurrence of great or destructive seismic disturbances.

1. Dr. C. Davison found from Mallet's Catalogue a similar reversal of the maximum epoch in the annual variation of *destructive* and *slight* earthquakes. See Trans. Roy. Soc. Lond., Vol. 184 (1893), p. 1116.

IV. Distribution of Destructive Earthquakes in Historic Times of Japan.¹

9. The distribution in time of the destructive earthquakes in Japan¹ from the 8th century to the present time is graphically shown in fig. 5, from which it will be observed that the distribution was not uniform, but was rather in groups.

10. The epochs of the minimum frequency of destructive earthquakes selected from the epoch of the Tokugawa Shogunate, which dates from the beginning of the 17th century, were as follows:—in the interval of 31 years between the earthquake at Ko-ori (in Iwashiro) of the 7th October, 1731, and the earthquake in Sado of the 31st October, 1762, there was only the earthquake at Takata (in Echigo) of the 20th May, 1751; and in the interval of 31 years and 3 months between the Shinano earthquake of the 23rd April, 1858, and the Kumamoto earthquake of the 28th July 1889, there was only the earthquake in Iwami of the 14th March, 1872.

11. On the other hand, the most remarkable epochs of maximum frequency of destructive earthquakes were as follows: in the interval of 5 years and 5 months between March, 1644, and the 3rd August, 1649, there were nine destructive earthquakes, giving as average one in every 8 months; in the interval of 11 years and 5 months between the 21st April, 1659, and the 28th September, 1670, there were twelve destructive earthquakes, giving as average one in 12½ months; in the interval of 5 years and 1 month between the 11th March, 1853, and the 23rd April, 1858, there were eight destructive earthquakes, which give one to every 9 months; and, finally, in the interval of 9 years, bet-

1) Formosa, Liu-kiu Islands and Hokkaido excepted.

ween the 28th July, 1889, and the 10th August, 1898, there were eleven destructive earthquakes, giving as average one in every 10 months.

12. If we count, instead of the actual number of destructive earthquakes, the number of years in which one or more occurred, we find 78 instances in the interval of 299 years from the beginning of the 17th century to the present time; the maximum number of destructive earthquakes in one year, namely three, having occurred in 1649 and 1662. In other words, 26 years in every 100 were each visited, on the average, by one, two, or three destructive earthquakes, the other 74 years remaining free from such seismic disturbances.

13. From fig. 5 it will be seen that destructive earthquakes happen sometimes singly or isolated, but tend to occur in groups in epochs of maximum frequency.

As a trial, I have in Table IX divided the 154 destructive earthquakes since the beginning of the 14th century into 41 groups, whose longest duration was 15 years, the maximum earthquake number included in one group being 12.

TABLE IX.

Time Distribution of Destructive Earthquakes in Japan.¹

(From the 14th century to the present time).

Time interval.	Number of destructive eqkes.	Mean epoch.	Difference	Time interval.	Number of destructive eqkes.	Mean epoch.	Difference.
yr. month yr. month		yr. month	yrs.	yr. month yr. month		yr. month	yrs.
1325.12-1331. 8	3	1329. 9	21.	1624. 6-1639.11	6	1632. 0	17.
1350. 7	1	1350. 7	11.	1644. 3-1649. 8	9	1647. 9	16.
1361. 6	2	1361. 8	14.	1659. 4-1670. 7	12	1664.11	17.
1375. 5	1	1375. 5	13.	1676. 7-1677. 4	2	1677. 0	12.
1388. 2	1	1388. 2	13.	1683. 6-1686.10	4	1685. 0	8.
1400. 9	1	1400. 9	7.	1694. 6-1709. 3	8	1702. 8	18.
1407. 2-1408.11	3	1408. 1	15.	1714. 4-1718. 8	2	1716. 6	14.
1420. 9-1425.11	2	1423. 4	19.	1723.12-1731.10	5	1728. 3	12.
1433. 2-1454.12	9	1442. 9	24.	1751. 5	1	1751. 5	23.
1466. 5	1	1466. 5	10.	1762.10-1769. 8	3	1766. 3	15.
1474. -1479. 9	3	1476. 5	20.	1778. 2-1782. 8	2	1780. 5	14.
1489. 5-1502. 1	9	1496. 3	16.	1792. 4	1	1792. 4	12.
1507. 4-1517. 7	8	1512. 5	13.	1798. 7-1804. 7	3	1802. 1	10.
1525.9	1	1525. 9	7.	1810. 2-1815. 3	2	1812.10	11.
1532.3	1	1532. 3	17.	1819. 8-1821.12	2	1820.10	8.
1544. 5-1555. 9	5	1549. 8	14.	1828.12-1835. 8	5	1832. 3	11.
1563. 2-1563.12	2	1563. 7	15.	1841. 5-1844. 5	1	1842.11	11.
1578.12	1	1578.12	8.	1853. 3-1858. 4	8	1856. 5	14.
1585. 7-1589. 3	4	1586. 9	13.	1872. 3	1	1892. 3	16.
1596. 9-1605. 2	4	1599. 9	15.	1889. 7-1898. 8	11	1894.10	23.
1611. 9-1616. 9	4	1614. 9		Mean.....			13½

1) Formosa, Liu-kiu Islands and Hokkaido excepted.

The *mean epochs* given in the third column of Table IX, each of which indicates the mean of the dates of those earthquakes included in one group, may be interpreted as representing the epochs of greatest activity of destructive shocks. Again, the *differences* given in the fourth column of the same table, which are the intervals between the successive *mean epochs*, vary between 7 and 23 years, the average value being $13\frac{1}{2}$ years. The conclusion is that the epochs of maximum activity of destructive shocks would recur on the average in every 13 or 14 years.

14. It is impossible to determine whether there was in historic times a permanent variation in the frequency of destructive earthquakes in Japan as a whole; the increase of earthquake records in later centuries implying, of course, not necessarily any such variation. The frequency seems, however, to be subject to certain fluctuations of long period. Thus the curve in fig. 6, which represents the variation of the 10-yearly activity of destructive earthquakes in Japan, indicates a maximum in the middle of the 17th century, and one minimum in the middle of the 16th and another in the middle of the 18th century, the length of the period being in this case about 200 years. Again, according to fig. 7, which shows for the whole country the variation of the activity of destructive earthquakes in every half century, since the latter half of the 6th century (see Table XII), there seems to exist, in the interval of about 1000 years between the middle of the 8th century and that of the 18th a more or less definite series of 5 maxima and minima, giving a period of an average length of 200 years.

15. To see whether the long-period fluctuations of *ordinary* small shocks and destructive earthquakes take place simultaneously, I shall compare the curve of the half-century activity

of destructive earthquakes in Japan, fig. 7, with that of the total seismic activity for Kyoto, fig. 9. It will be observed that both curves present maxima and minima in nearly the same epochs. No similar result, however, is to be obtained when we examine the thing more in detail. Thus, the curve of the decennial activity of destructive earthquakes in Japan, fig. 6, presents a *minimum* at the middle of the 18th century, but the curve of frequency of small earthquakes at Kyoto since the 16th century, fig. 8, presents a *maximum* at the same epoch. When considered in a general way, therefore, destructive earthquakes and ordinary small shocks seem to present the maxima and minima of their frequency in nearly the same epochs; but, when examined in detail, the maxima of short-period fluctuations in the frequency of one kind of earthquakes may happen, as has been found to be the case with the annual variation, simultaneously with the minima in the frequency of the other kind of earthquakes and *vice versa*. It may be observed that these two conclusion are not contradictory to each other, the case being somewhat analogous to the relation of volcanoes and earthquakes. It is well known that a country, rich in active volcanoes, is also very frequently disturbed by earthquakes. But when we examine different parts of such a country in detail, it will be found that the immediate vicinity of an active volcano is rarely affected by destructive earthquakes.

V. Geographical Distribution of Destructive Earthquakes in Japan.

16. The geographical distribution of destructive earthquakes in Japan is given in Table X, the figures in the second and third columns giving the numbers of earthquakes which took place

in each province since the earliest times (5th century), and since the 17th century. See figs. 20 and 21.

TABLE X.

Geographical Distribution of Destructive Earthquakes in Japan.¹

Province.	Number of destructive eqkes, from the 5th century to the present time.	Number of destructive eqkes, from the 17th century to the present time.	Average interval of time.	Province.	Number of destructive eqkes, from the 5th century to the present time.	Number of destructive eqkes, from the 17th century to the present time.	Average interval of time.
			years.				years.
Yamashiro	34	10	30	Hitachi	6	1	
Yamato	21	6	50	Omi	10	7	43
Kawachi	15	8	37	Mino	10	6	50
Izumi	9	4	75	Hida	2	0	
Settsu	16	7	43	Shinano	12	9	33
Iga	7	4	75	Kotsuke	3	0	
Ise	12	7	43	Shimotsuke	11	7	43
Shima	4	3	100	Iwaki	4	2	
Owari	8	6	50	Iwashiro	22	4	75
Mikawa	15	9	33	Rikuzen	7	7	43
Totomi	13	8	37	Rikuchiu	4	4	75
Suruga	13	8	37	Mutsu.	5	5	60
Kai	9	3	100	Uzen	3	3	100
Izu	8	5	60	Ugo	4	3	100
Sagami	28	11	27	Wakasa	4	3	100
Musashi	18	14	21	Echizen	6	5	60
Awa (in Tokai- do)	3	3	100	Kaga	3	2	
Kazusa	3	3	100	Noto	2	2	
Shimosu	6	3	100	Etchii	2	1	

1) In the seven cases at the end of the list (marked with asterisks) the districts are given in too wide and indefinite terms. These have therefore been excluded in the construction of the maps, figs. 20 and 21.

Province.	Number of destructive earthquakes, from the 5th century to the present time.	Number of destructive earthquakes, from the 17th century to the present time.	Average interval of time, years.	Province.	Number of destructive earthquakes, from the 5th century to the present time.	Number of destructive earthquakes, from the 17th century to the present time.	Average interval of time, years.
Echigo	7	5	60	Hizen	5	5	60
Sado	5	5	60	Higo	5	2	
Kii	13	6	50	Hinga	4	4	75
Awaji	4	2		Osumi	4	2	
Awa (in Shi- koku.	5	3	100	Satsuma	5	2	
Santuki	5	3	100	Iki	0	0	
Iyo	6	5	60	Tsushima	4	3	100
Tosa	5	4	75	Oshima	4	4	75
Tanba	5	3	100	Shiribeshi	0	0	
Tango	2	2		Ishikari	1	1	
Tajima	0	0		Teshiwo	1	1	
Inaba	2	2		Kitami	0	0	
Iloki	1	1		Iburi	2	2	
Izumo	2	1		Hitaka	0	0	
Iwami	3	3	100	Tokachi	0	0	
Harima	4	3	100	Kushiro	2	2	
Minasaka	1	1		Nemuro	3	3	
Bizen	2	2		Chishima	2	2	
Bitchu	2	2		Liu-kiu	2	2	
Bingo	2	2		Kinai*	1	0	
Aki	3	3	100	Dewa*	1	0	
Suwo	1	1		Mutsu*	1	0	
Nagato	2	2		Kiushiu*	2	2	
Chikuzen	3	2		Chikushi*	1	0	
Chikugo	1	1		Yezo*	1	1	
Buzen	1	1		Several vinces.* pro-	5	0	
Bungo	2	2					

17. *Distribution of destructive earthquakes since the earliest times.* The maximum number of 34 occurred in Yamashiro, due without doubt to that province's containing Kyoto, which was the capital from the end of the 8th century till 1867. Sagami and Musashi, for which the numbers of destructive earthquakes were respectively 28 and 18, seem really to have been the regions most disturbed in Japan, as the greatest numbers of destructive earthquakes since the 17th century occurred in these two provinces. To sum up: no destructive earthquake occurred in the seven provinces of Iki, Oki, Tajima, Shiribeshi, Kitami, Hitaka and Tokachi; only one in the seven provinces of Chikugo, Buzen, Suwo, Hoki, Mimasaka, Ishikari and Teshio; more than eleven in the fourteen provinces of Yamashiro, Yamato, Kawachi, Settsu, Kii, Ise, Shinano, Mikawa, Totomi, Suruga, Sagami, Musashi, Shimotsuke and Iwashiro; between six and ten in the thirteen provinces of Iyo, Izumi, Iga, Omi, Echizen, Mino, Owari, Kai, Izu, Shimosha, Hitachi, Echigo and Rikuzen; and between two and five in the remaining forty-two provinces.

18. With respect to the distribution of destructive earthquakes in the interval between the 17th century and the present time, the maximum number of 14 occurred in Musashi, and the next greatest number, that of 11, in Sagami. Between six and ten destructive earthquakes occurred in the sixteen provinces of Yamashiro, Yamato, Kawachi, Settsu, Kii, Iga, Ise, Omi, Mino, Owari, Mikawa, Totomi, Suruga, Shinano, Shimotsuke and Rikuzen; only one in the ten provinces of Chikugo, Buzen, Suwo, Izumo, Hoki, Mimasaka, Etchui, Hitachi, Ishikari and Teshio; none in the nine provinces of Iki, Oki, Tajima,

Hida, Kotsuke, Shiribeshi, Hitaka, Tokachi and Kitami; and between two and five occurred in the remaining forty-six provinces.

19. *The area of earthquake disturbance.* Let us for the sake of convenience distinguish destructive earthquakes, according to the magnitude of the area of disturbance, into two kinds, namely, *local* earthquakes, in which the area of destructive motion was confined to only one province, and *non-local* earthquakes, in which the area extended over several provinces. According to this convention, the 222 destructive earthquakes contained in Table I may be divided into 149 local and 73 non-local ones, the ratio of these two numbers being as 2:1. Further, from examination of Table I, it will be seen that the provinces of Osumi, Satsuma, Higo, Hizen, Chikuzen, Tsuchishima, Iwami, Izumo, Kaga, Noto, Sado, Echigo, Shinano, Shimotsuke, Iwashiro, Uzen, Ugo, Ishikari and Teshiwo were generally disturbed by local shocks, non-local ones originating, with the exceptions of Shinano and Echigo, very rarely in these districts. On the other hand, Hiuga, Bungo, Tosa, Kii, Mino, and the provinces of Kinai and Tokaido were often disturbed by great non-local shocks, whose origins were generally situated off the eastern coast of Japan, and which were probably caused by faults formed parallel to the latter.

The three north-eastern provinces of Rikuzen, Rikuchu and Nemuro were often disturbed by great earthquakes of sub-oceanic origins. The areas of destructive motion in these cases seems never to have extended to the south of Hitachi and the Peninsula of Kazusa and Awa. Now, as is well known, the group of the Japanese islands forms an arc, whose concavity is turned towards the Japan Sea, and the general geographical distribution of destructive earthquakes in Japan may be summarised

as follows. The provinces on the concave or Japan-Sea side of the arc were disturbed almost only by *local* shocks ; while those on the convex or Pacific side of the arc were often disturbed by great *non-local* ones, whose origins were situated in the Ocean and which caused sometimes fearful sea-waves. Of the provinces in the central portion of the Main Island, Mino, Shinano, Shimotsuke and Iwashiro become often the seats of local destructive earthquakes. But the two other provinces of Kotsuke and Hida were very seldom disturbed by destructive earthquakes, and form, together with Tajima and a few provinces in Sanyo-do, the regions seismically most stable in the Main Island.

20. The figures in the 14th column of Table X give, for different provinces, the average intervals of time between two successive destructive earthquakes, as deduced from the numbers in the 3rd column of the same Table. Among others, the mean interval is for Musashi 21 years, and for Sagami 27 years.

VI. Kyoto Earthquakes.

21. Kyoto was the capital of the Empire during the 1070 years between 797 and 1867. The records of earthquakes in this city is therefore most complete, and includes 1308 shocks, of which 34 were destructive, 194 strong, and the remaining 1090 slight.

I shall consider the seismicity in Kyoto under the following three heads : firstly, destructive earthquakes ; secondly, strong and slight earthquakes ; and thirdly, the annual variation of seismic frequency.

22. *Destructive earthquakes in Kyoto.* In Kyoto, there have been since the 9th century (Table XI) 34 destructive earthquakes, which happened therefore on the average once in about 30 years. Their distribution in time is illustrated in fig. 10.

TABLE XI.

Number of Destructive Earthquakes in Kyoto.

Century.	Number of destructive earthquakes.	Century.	Number of destructive earthquakes.
IX	5	XV	6
X	3	XVI	2
XI	4	XVII	4
XII	3	XVIII	1
XIII	1	XIX	4
XIV	1		

As will be observed from fig. 10, two destructive earthquakes happened sometimes in one year, but at other time none happened in an interval of more than 50 or 100 years. Examples of the latter case are the following: intervals of 65 years between the 22nd July 976 and the 25th August 1041, of 105 years between the 26th August 1245 and the 6th July 1350, of 119 years between the 29th May 1466 and 18th December 1585, and of 123 years between the 28th October 1707 and the 19th August 1830.

In Table XII, the 34 destructive earthquakes in Kyoto are divided into five groups. The interval between the mean epochs of the successive groups varies between 209 and 285 years, giving the average of 240.

As the total number of destructive earthquakes in Kyoto is only 34, it is impossible to determine whether there was any permanent variation in the activity of such earthquakes. But it seems probable that there was nothing of the kind. Thus dividing the interval of 1100 years from the 9th century to

the present time into two equal parts, we find that there were in the first 550 years seventeen, and in the second 550 years also seventeen destructive earthquakes.

TABLE XII.

Time Distribution of Destructive Earthquakes in Kyoto.

Time Interval.		Number of destructive eqkes.	Mean epoch.	Difference.
From	yr. month day to yr. month day		yr. month	years.
	827. 8.11 to 976. 7.22	8	896. 5	236
,,	1041. 8.25 , 1245. 8.26	8	1132. 0	289
,,	1350. 7. 6 , 1466. 5.29	7	1421. 0	228
,,	1585.12.18 , 1707.10.28	7	1649. 4	209
,,	1830. 8.19 , 1891.10.28	4	1858. 0	
Mean...240				

23. *Strong and small shocks in Kyoto.* In Kyoto there have been since the 9th century 228 strong and destructive earthquakes, whose distribution in time will be evident from fig. 11, the half-century numbers being given in the 3rd column of Table XIII. The total numbers of small earthquakes in Kyoto, which happed in the time interval between the 18th century and the 3rd year of Kei-o (1867), is 1090, the half-century numbers being given in the 4th column of Table XIII. Fig. 9 shows the variation of the general seismic activity in Kyoto from the earliest times, x denoting time in units of 50 years, and y the total seismic activity corresponding to x , obtained by adding together the numbers of small, strong and destructive earthquakes multiplied by coefficients respectively equal to 1,2 and 2.

TABLE XIII.

Half-century Number of Earthquakes in Japan and Kyoto.

Time interval.	Destructive eqkes in Japan.	Destructive and strong eqkes in Kyoto.	Small eqkes in Kyoto.	Total activity in Kyoto.
400- ^{yr.} 449 ^{yr.}	1			
450- 499	0			
500- 549	0			
550- 599	1			
600- 649	0			
650- 699	2			
700- 749	8			
750- 799	2		3	3
800- 849	5	6	88	100
850- 899	11	15	327	357
900- 949	2	3	55	61
950- 999	1	11	15	37
1000-1049	1	4	3	11
1050-1099	3	8	21	37
1100-1149	1	7	20	34
1150-1199	4	12	9	33
1200-1249	8	11	18	40
1250-1299	5	2	6	10
1300-1349	3	11	23	45
1350-1399	5	33	79	145
1400-1449	14	31	90	152
1450-1499	11	29	68	126
1500-1549	15	17	38	72
1550-1599	11	8	35	51
1600-1649	21	7	70	84
1650-1699	21	4	26	34
1700-1749	12	2	42	46
1750-1799	8	2	46	50
1800-1849	13	0	5	5
1850-1898	20	5	—	—
Sum	209	228	1090	

Both fig. 9 and fig. 11 indicate a well pronounced maximum in the 15th century, followed by a minimum in the latter half of the 17th and the first half of the 18th century. The seismic activity in Kyoto at the present time seems to be on its way to a second maximum, which may happen possibly 150 or 200 years hence. Anyway it seems not prudent to conclude that the seismic activity in Kyoto is gradually dying away¹. The curve of total seismic activity in Kyoto, fig. 9, indicates a well-pronounced maximum in the latter half of the 9th century, in which interval the number of small shocks alone amounted to 327. We can not, however, conclude from this at once that the seismic activity in Kyoto reached really its *absolute* maximum in the 9th century. For, the predominating element of the curve in fig. 9 is formed by small earthquakes, whose recorded number, it must be observed, would largely depend on the state of the development of literature of the times. As the 9th century was one of the epochs in Japanese history, in which our literature greatly flourished, the record of earthquakes in this century is doubtless much more complete than in some others. On the other hand, the number of records of destructive and strong earthquakes would be influenced to a comparatively insignificant amount by the state of the times; and according to fig. 11, which illustrates the time-distribution of 228 destructive and strong earthquakes in Kyoto, the maximum in the latter half of the 9th century was much smaller than that in the 15th century.

24. Finally I give in Table XIV, for the sake of reference, the yearly numbers of earthquakes in Kyoto during 13 years between 1885 and 1897. The numbers for the two years, 1891

1) See Professor John Milne's paper: Note on the Great Earthquakes in Japan. *Trans. Scis. Soc. Japan*. Vol. III.

and 1892, are, owing to the after-shocks of the great Mino-Owari earthquake of the 28th October 1891, unusually great. The mean yearly number of earthquakes in Kyoto, deduced from the other eleven years, is 5.

TABLE XIV.

Yearly Earthquake Numbers in Kyoto. (Between 1885 and 1897).

Year.	Number of eqkes.	Year.	Number of eqkes.
1885	5	1892	25
1886	2	1893	5
1887	6	1894	6
1888	5	1895	14
1889	2	1896	9
1890	2	1897	3
1891	102		

25. *The annual variation of seismic frequency in Kyoto.* The monthly distribution of 228 strong earthquakes¹ in Kyoto is shown in Tables XV, XVI and XVII, and illustrated in figs. 13 and 15.

According to Table XV, the maximum monthly numbers of 29 and 28 occurred respectively in August and December, and the minimum of 13 both in February and September, the ratio of the greatest and least numbers being as 2.2:1. According to Table XVI, the maximum seasonal number of 65 occurred in Summer and the minimum of 52 in Autumn, the ratio of the two numbers being as 1.3:1. Comparing Tables XV and XVI with Tables III and IV, we find that the months and seasons of the maximum and minimum seismic frequencies were nearly identical for strong earthquakes in Kyoto and

1) Including 34 destructive earthquakes.

destructive earthquakes in Japan, the ratio of the maximum and minimum for the former being, however, smaller than that for the latter.

TABLE XV.

Monthly Distribution of 228 Destructive and Strong Earthquakes in Kyoto.

Month.	Number of earthquakes.
I	16
II	13
III	22
IV	14
V	18
VI	16
VII	20
VIII	29
IX	13
X	17
XI	22
XII	28

TABLE XVI.

Seasonal Distribution of 228 Destructive and Strong Earthquakes in Kyoto.

Season.	Number of earthquakes.
Spring { March. April. May.	54
Summer { June. July. August.	65
Autumn { September. October. November.	52
Winter { December. January February.	57

TABLE XVII.

Semi-annual Distribution of 228 Destructive and Strong Earthquakes in Kyoto.

Division of the year.	Number of earthquakes.
Warmer months { April, May, June, July, August, September.	110
Colder Months { October, November, December, January, February, March.	118

26. The monthly distribution of 1088 small earthquakes in Kyoto, whose dates are exactly known, is shown in Tables XVIII, XIX and XX, and illustrated in figs. 12 and 14. According to Table XVIII, the maximum monthly number of 110 occurred in March, and the minimum of 74 in September, the ratio of the two numbers being as 1.5:1. Comparing fig. 12 with fig. 13, we find that for Kyoto the August maximum, which is very well marked in the frequency of the strong earthquakes, is reduced to a mere trace in the case of the small earthquakes. According to Table XIX, the maximum seasonal number of 307 occurred in Spring, and the minimum of 252 in Winter, the ratio of the two numbers being as 1.2:1.

Finally, according to Table XX, there exists no difference between the number of small earthquakes in Kyoto for the warmer and colder halves of the year.

The occurrence of minimum frequencies of Kyoto small earthquakes in Autumn and Winter does not agree with the annual variation of ordinary small earthquakes in Japan, illustrated in fig. 4, which presents the minimum in Summer. There may possibly exist some seismic peculiarity inherent in the region about Kyoto, causing its annual variation to differ from that for other parts of Japan.

TABLE XVIII.

Monthly Distribution of 1088
Small Earthquakes in Kyoto.

Month.	Number of earthquakes.
I	79
II	82
III	110
IV	102
V	95
VI	91
VII	87
VIII	95
IX	74
X	87
XI	95
XII	91

TABLE XIX.

Seasonal Distribution of 1088
Small Earthquakes in Kyoto.

Season.	Number of earthquakes.
Spring { March. April. May.	307
Summer { June. July. August.	273
Autumn { September. October. November.	256
Winter. { December. January. February.	252

TABLE XX.

Semi-annual Distribution of 1088 Small Earthquakes
in Kyoto.

Division of the year.	Number of earthquakes.
Warmer months { April, May, June, July, August, September.	544
Colder months { October, November, December, January, February, March.	544

27. *Secular variation of seismic activity in Kyoto.* Tables XXI and XXII give respectively the yearly numbers of earthquakes in Kyoto for the two most disturbed epochs, namely, the 9th century and the time interval between 1340 and 1609, the *total activity* for each year being the sum of the numbers of small, strong and destructive earthquakes multiplied respectively with the coefficients 1, 2 and 2. The results contained in these two tables are illustrated in figs. 16 and 17, from which it will be seen that the seismic activity presents a series of fluctuations of periods varying between a few years and a few dozen years. The curve for the 9th century indicates more or less definitely a period of the average length of $6\frac{1}{2}$ years. In figs. 16 and 17, each of the small circles (○) on the abscissa axis indicates a destructive earthquake in Kyoto, and it may be observed that about the year 1360 small earthquakes were very frequent in Kyoto, but these were accompanied by no destructive shock.

TABLE XXI.

Yearly Earthquake Numbers in Kyoto. (Between 800 and 899).

Year.	Slight.	Strong.	Destructive.	Total activity.	Year.	Slight.	Strong.	Destructive.	Total activity.
800				0	826	7			7
801				0	827	2		1	4
802				0	828	5	1		7
803				0	829	3	1		5
804	2			2	830	4			4
805	3			3	831	3			3
806	1			1	832	7			7
807		1		2	833	1	1		3
808				0	834	1			1
809				0	835	1			1
810	1			1	836	2	1		4
811				0	837	3			3
812	1			1	838	2			2
813				0	839	2			2
814				0	840	2			2
815				0	841				0
816	1			1	842	6			6
817				0	843	3			3
818	3			3	844				0
819				0	845	2			2
820				0	846	1			1
821				0	847				0
822				0	848	9			9
823	2			2	849	5			5
824	1			1	850	8			8
825	2			2	851	11			11

Year.	Slight.	Strong.	Destruc- tive.	Total activity.	Year.	Slight.	Strong.	Destruc- tive.	Total activity.
852	10			10	876	6			6
853	10			10	877	3	2		7
854	6			6	878	6			6
855	16			16	879	11			11
856	19		1	21	880	10	1		12
857	13			13	881	15	1	1	19
858	6			6	882	4			4
859	5	1		7	883	4			4
860	13			13	884	4			4
861	8			8	885	5			5
862	16	1		18	886	3	2		7
863	8			8	887	4		1	6
864	3	1		5	888				0
865	8			8	889				0
866	7			7	890				0
867	12			12	891				0
868	7		1	9	892				0
869	5			5	893				0
870	7			7	894				0
871	6			6	895				0
872	13			13	896				0
873	13	1		15	897				0
874	12			12	898		1		2
875	9	1		11	899	1			1

TABLE XXII.

Yearly Earthquake Numbers in Kyoto. (Between 1340 and 1609.)

Year.	Slight.	Strong.	Destructive.	Total activity.	Year.	Slight.	Strong.	Destructive.	Total activity.
1340		1		2	1366				0
1341	1	1		3	1367		3		6
1342	1			1	1368	2			2
1343				0	1369		1		2
1344	2			2	1370				0
1345	2			2	1371	1	2		5
1346		1		2	1372	1			1
1347	11	2		15	1373	4	2		8
1348	2			2	1374				0
1349	2	1		4	1375	2			2
1350	7	2	1	13	1376		1		2
1351	4	1		6	1377				0
1352	3			3	1378		1		2
1353				0	1379		1		2
1354				0	1380	1			1
1355	1			1	1381	3			3
1356	5			5	1382				0
1357	5			5	1383	3	1		5
1358	8	2		12	1384				0
1359	2			2	1385				0
1360	2			2	1386				0
1361	3	5		13	1387				0
1362	10	2		14	1388			1	2
1363	3	5		13	1389				2
1364	6			6	1390		1		0
1365				0	1391		1		2

Year.	Slight.	Strong.	Destruc- tive.	Total activity.	Year.	Slight.	Strong.	Destruc- tive.	Total activity.
1392				0	1421	1			1
1393				0	1422	2			2
1394				0	1423	8			8
1395	1	1		3	1424	1			1
1396				0	1425	4	4	1	14
1397				0	1426	14	1		16
1398	2			2	1427	4			4
1399				0	1428		1		2
1400	1		1	3	1429	1			1
1401	1			1	1430				0
1402		1		2	1431	3			3
1403	3			3	1432				0
1404				0	1433	4	4		12
1405	1	2		5	1434	5	1		7
2406				0	1435	6	1		8
1407		1		2	1436	1			1
1408	2		1	4	1437	2			2
1409	2			2	1438	3			3
1410	2	1		4	1439	1	1		3
1411	1	2		5	1440		1		2
1412	4	1		6	1441				0
1413		1		2	1442	1	1		3
1414				0	1443	4			4
1415				0	1444		1		2
1416				0	1445			1	2
1417				0	1446	1			1
1418				0	1447		1		2
1419	2			2	1448				0
1420		1		2	1449	5		1	7

Year.	Slight.	Strong.	Destructive.	Total activity.	Year.	Slight.	Strong.	Destructive.	Total activity.
1450	3			3	1479	1			1
1451	3			3	1480				0
1452		1		2	1481	2			2
1453				0	1482	2			2
1454				0	1483				0
1455				0	1484				0
1456		1		2	1485				0
1457	1			1	1486	1			1
1458	1	1		3	1487	1			1
1459	1			1	1488				0
1460	9	3		15	1489	3	3		9
1461				0	1490				0
1462		1		2	1491	2			2
1463				0	1492		1		2
1464		1		2	1493	2	2		6
1465	1			1	1494	2	1		4
1466	4		1	6	1495	1			1
1467	5	2		9	1496	1			1
1468	5	1		7	1497		1		2
1469				0	1498	4	3		10
1470	1			1	1499	8	1		10
1471		2		4	1500	7			7
1472				0	1501	1			1
1473				0	1502				0
1474				0	1503	2			2
1475	2	1		4	1504		1		2
1476				0	1505	1			1
1477	2	1		4	1506	2	1		4
1478				0	1507	1	2		5

Year.	Slight.	Strong.	Destructive.	Total activity.	Year.	Slight.	Strong.	Destructive.	Total activity.
1508	1			1	1537				0
1509	2			2	1538				0
1510	2	1		4	1539				0
1511	5			5	1540				0
1512	3	1		5	1541				0
1513				0	1542	1			1
1514	2	2		6	1543				0
1515				0	1544				0
1516		1		2	1545				0
1517		2		4	1546				0
1518				0	1547				0
1519		1		2	1548				0
1520	1	1		3	1549		1		2
1521		1		2	1550	1			1
1522				0	1551				0
1523				0	1552				0
1524	1			1	1553				0
1525	1			1	1554	1			1
1526	2			2	1555				0
1527		1		2	1556		1		2
1528				0	1557		1		2
1529		1		2	1558	1			1
1530				0	1559				0
1531	1			1	1560				0
1532				0	1561	1			1
1533	3			3	1562	1			1
1534				0	1563	1			1
1535				0	1564	1	1		3
1536				0	1565	1			1

Year.	Slight.	Strong.	Destructive.	Total activity.	Year.	Slight.	Strong.	Destructive.	Total activity.
1566	1			1	1588	1			1
1567	1			1	1589				0
1568	5			5	1590				0
1569	1			1	1591				0
1570	3			3	1592				0
1571				0	1593	2			2
1572	2	1		4	1594				0
1573	1			1	1595		1		2
1574				0	1596		2	1	6
1575	1			1	1597				0
1576				0	1598	5			5
1577				0	1599	4			4
1578				0	1600		4		8
1579				0	1601	2			2
1580				0	1602	8			8
1581				0	1603	3			3
1582	1			1	1604	10	1		12
1583				0	1605	2			2
1584				0	1606	1			1
1585			1	2	1607	1			1
1586				0	1608				0
1587				0	1609	3			3

28. *Earthquakes in Yedo (Tokyo)*. In Yedo (Tokyo) there have been since the 17th century 12 destructive earthquakes whose time distribution is illustrated in fig. 18. They were most frequent in the first half of the 17th century, when there were seven in the interval of 34 years and 3 months between the 26th June 1615, and the 1st September 1649, the mean interval between two successive shocks being 4 years and 11 months. Especially in 1649, there were two destructive earthquakes. On the other hand, there was not one destructive earthquake in the interval of 79 years between the 31st December 1703 and the 23rd August 1782.

In the course of the 245 years between the 1st September 1649 and the 20th June 1894, there were in Yedo (Tokyo) five destructive earthquakes, the mean interval being 49 years. If we simply count all the destructive earthquakes since the 17th century, the average interval becomes 25 years.

29. For the sake of reference I give in Table XXIII the yearly earthquake numbers in Tokyo during the 23 years between 1876 and 1898.

TABLE XXIII.

Yearly Earthquake Numbers in Tokyo. (Between 1876 and 1898).

Year.	Number of eqkes.	Year.	Number of eqkes.
1876	56	1888	101
1877	71	1889	113
1878	50	1890	93
1879	70	1891	123 (Modified number 97)
1880	77	1892	73
1881	64	1893	59
1882	46	1894	101 (Modified number 85)
1883	32	1895	122
1884	68	1896	216 (Modified number 184)
1885	68	1897	157 (Modified number 136)
1886	54	1898	
1887	80	Mean 82	

The great earthquake numbers for October 1891, March 1894, June 1896, and August 1897 were due to the after-shocks of four great earthquakes, which took place respectively in these four months. To obtain proper numbers for the four years concerned, the numbers for the above four months have been subtracted from the total numbers of the respective years, the remainder in each case being then multiplied by the factor $\frac{12}{11}$.

The results thus obtained, which are entered as *modified numbers*, have been utilised in drawing the curve of the yearly seismic frequency in Tokyo, fig. 19. The minima occurred in 1883 and 1893, and the maxima in 1880, 1889 and 1896. The

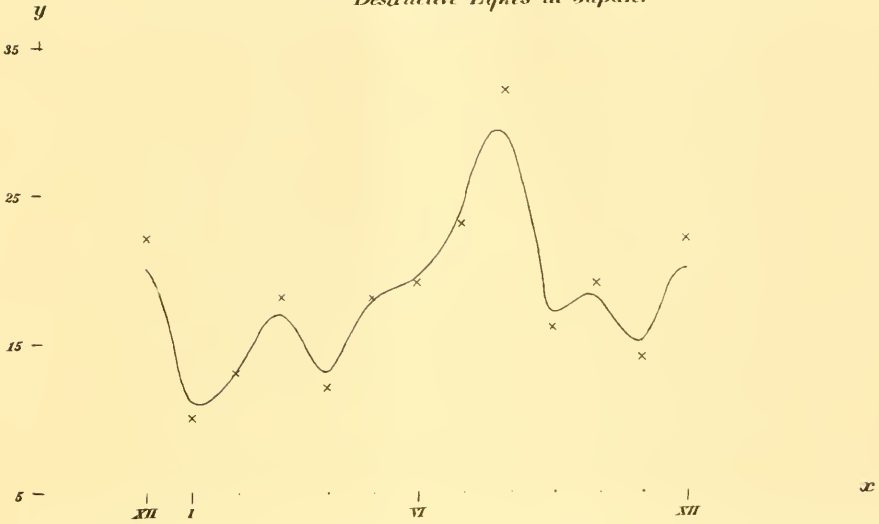
maximum in 1896 was the absolutely greatest in the time interval under consideration, the seismic frequency at the present time being probably on its way to a minimum. When looked at generally there seems to exist a period of long duration, the frequency, in the mean, increasing during the 23 years from 1878 to the present time.

December, 1898.

Seismological Institute,
Tokyo.

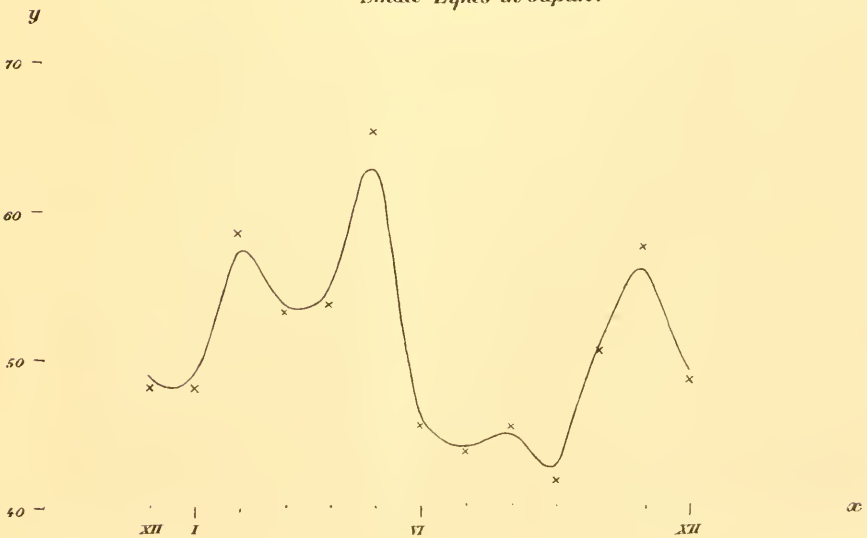


Fig. 1. Monthly Distribution of 216
Destructive Eqkes in Japan.



$x = \text{Month.}$
 $y = \text{Monthly number of destructive eqkes.}$

Fig. 2. Monthly Distribution of Ordinary
Small Eqkes in Japan.



$x = \text{Month.}$
 $y = \text{Mean monthly number of ordinary small eqkes.}$

Fig. 3. Seasonal Distribution of 216 Destructive Eqkes in Japan.

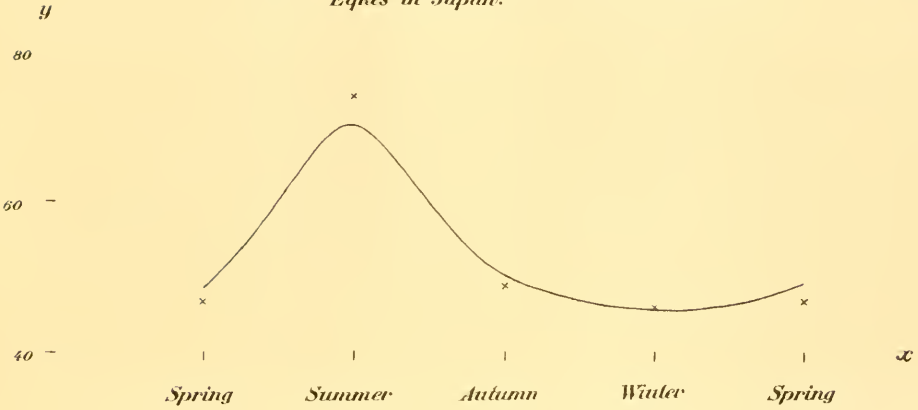


Fig. 4. Seasonal Distribution of Ordinary Small Eqkes in Japan.



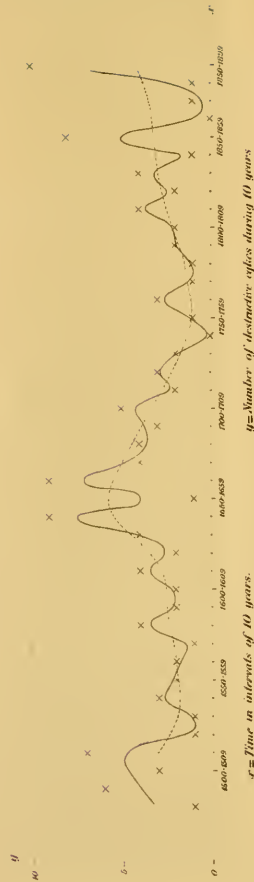
For Figs. 3 and 4,..... $\begin{cases} x = \text{Month.} \\ y = \text{Monthly number of eqkes.} \end{cases}$

Fig. 5. Time Distribution of Destructive Earthquakes in Japan; Formosa, Hokkaido and Liu-Kiu excepted. (From the 8th century to the present time.)



Each sign (x) marks a destructive earthquake; when two or more such shocks happened in a single year, the signs are put one over the other.
(b) is the continuation of (a), (c) that of (b), etc.

Fig. 6. Frequency of Destructive Earthquakes in Japan; Formosa, Hokkaido and Liu-Kiu excepted. (From the 16th century to the present time.)



The dotted line is drawn through mean positions of the curve.

Fig. 7. Frequency of Destructive Earthquakes in Japan; Formosa, Hokkaido and Liu-Kiu excepted. (From the 16th century to the present time.)

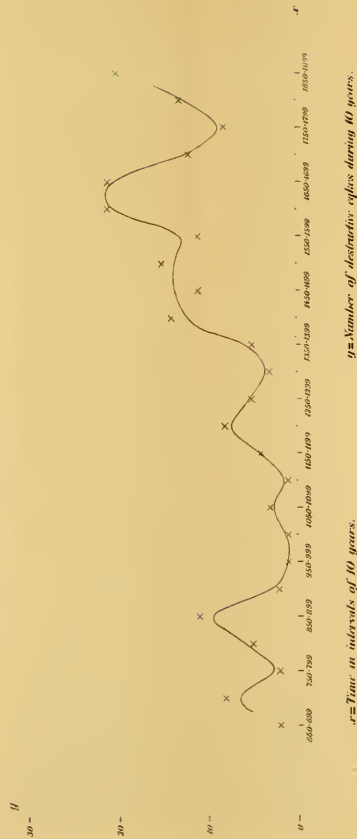
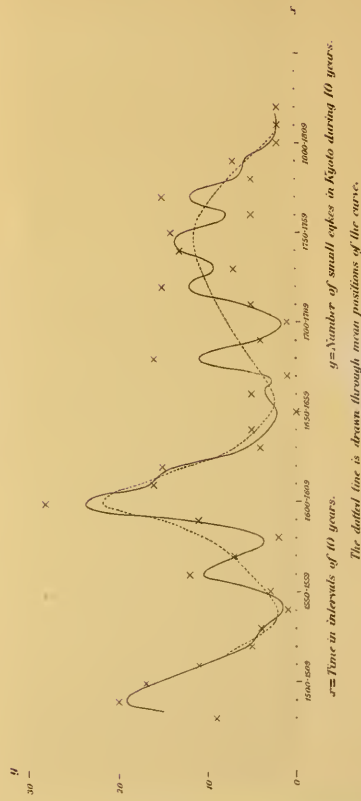
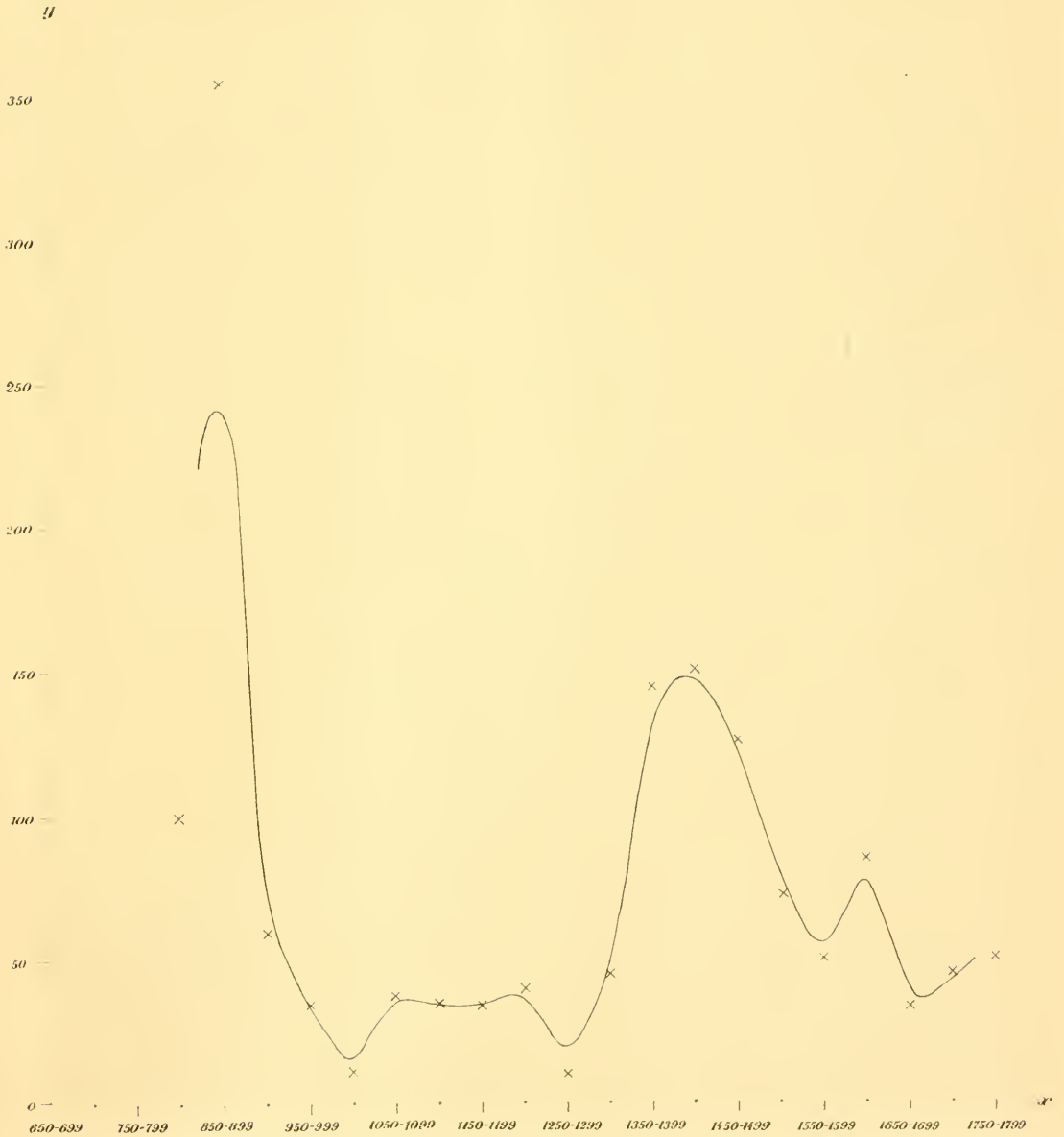


Fig. 8. Frequency of Small Earthquakes in Kyoto. (From the 16th to the 19th century.)



The dotted line is drawn through mean positions of the curve.

Fig. 9. Seismic Activity in Kyoto.
(From the 8th to the 18th century.)



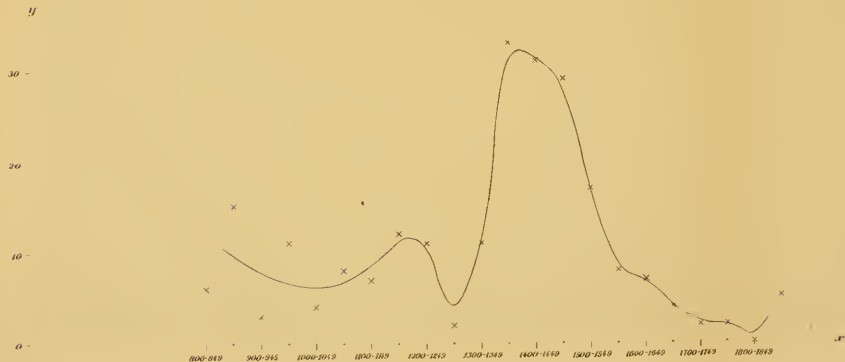
x = Time in intervals of 50 years.
 y = Number of eqkes during 50 years.

Fig. 10. Time Distribution of 34 Destructive Earthquakes in Kyoto.
(From the 8th century to the present time.)



Each sign (x) marks a destructive quake; when two such quakes happened in a single year, the signs are put one over the other.
(b) is the continuation of (a), and (c) that of (b).

Fig. 11. Frequency of Strong and Destructive Earthquakes in Kyoto
(From the 9th century to the present time.)



x = Time in intervals of 50 years.
 y = Total seismic activity during 50 years.

Fig. 12. Monthly Distribution of 1088
Small Eqkes in Kyoto.

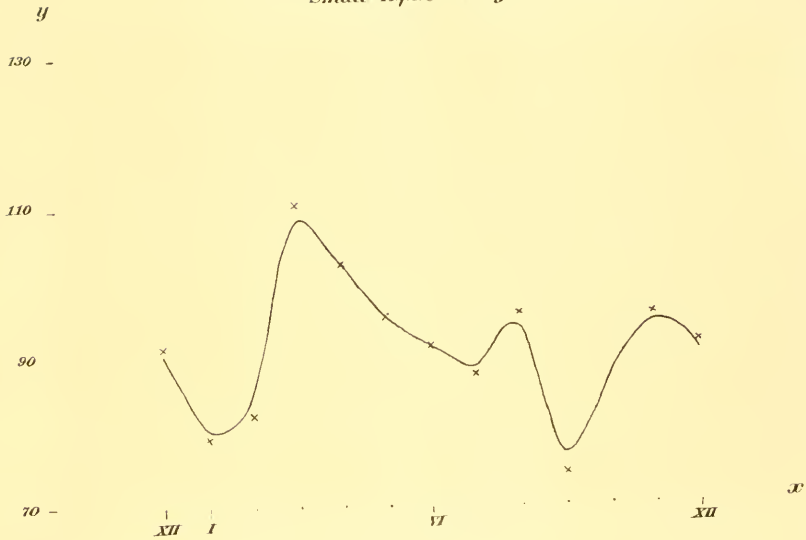
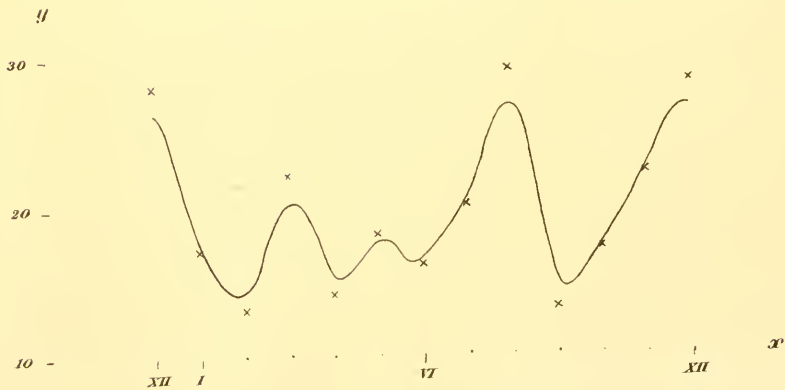


Fig. 13. Monthly Distribution of 228 Strong
and Destructive Eqkes in Kyoto.

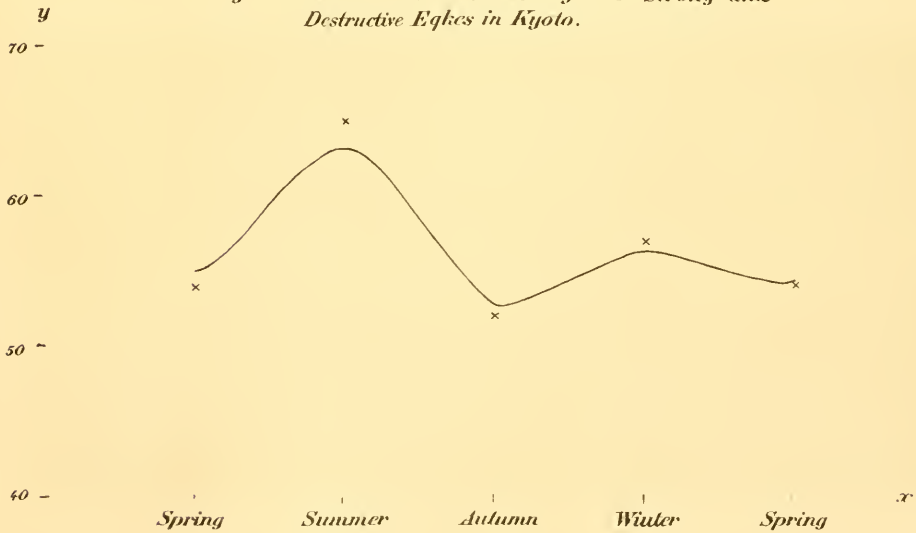


For Figs. 12 and 13 $\begin{cases} x = \text{Month.} \\ y = \text{Monthly number of eqkes.} \end{cases}$

Fig. 14. Seasonal Distribution of 1038 Small
Eqkes in Kyoto.

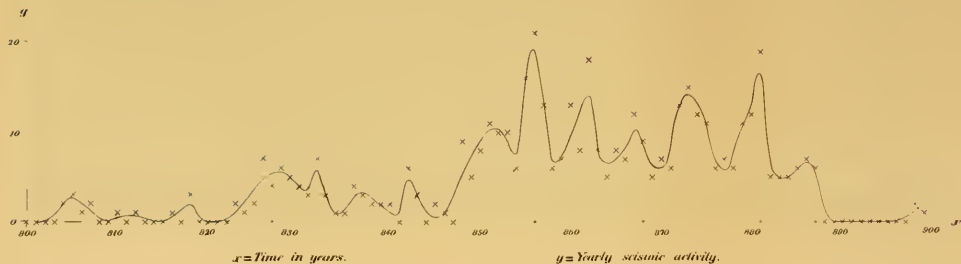


Fig. 15. Seasonal Distribution of 228 Strong and
Destructive Eqkes in Kyoto.



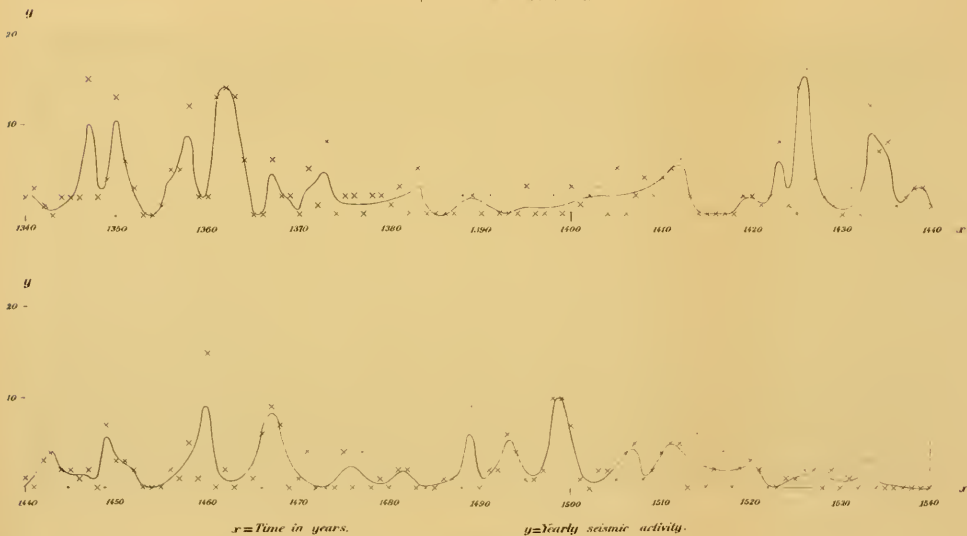
For Figs. 14 and 15,.....
 $\left\{ \begin{array}{l} x = \text{Season} . \\ y = \text{Seasonal number of eqkes} . \end{array} \right.$

Fig. 16. Seismic Activity in Kyoto during the 9th Century.



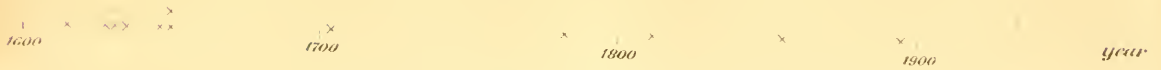
Each small circle (o) in the abscissa axis indicates a destructive cycle in the year specified.

Fig. 17. Seismic Activity in Kyoto.
(Between 1340 and 1540.)



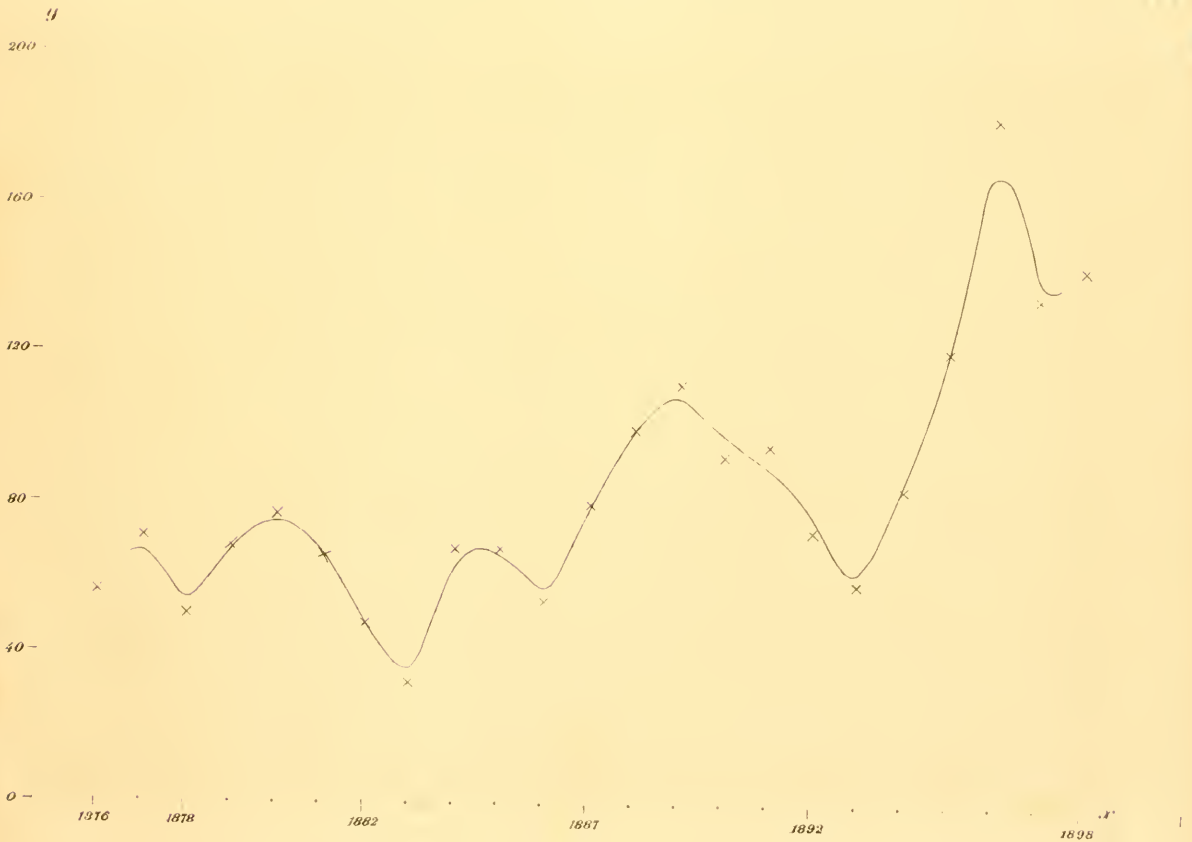
Each small circle (o) in the abscissa axis indicates a destructive cycle in the year specified.

Fig. 13. Time Distribution of 12 Destructive Earthquakes in Yedo (Tokyo)
(From the 17th century to the present time)



Each sign (x) marks a destructive earthquake; when two such shocks happened in a single year, the signs are put one over the other.

Fig. 19 Seismic Frequency in Tokyo.
(From 1876 to 1898.)



x = Time in years

g = Yearly number of earthquakes in Tokyo.

*Fig. 21. Distribution of
destructive eyles in Japan (Formosa
and Liu Kiu excepted).*

From the 17th century to the present time.

-) None. (Between 6 and 10.
○) Only one (Above 11.
○) Between 2 and 5.



MBL/WHOI LIBRARY



WH 19K4 /

2731

